PROJECT FINAL REPORT

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Project acronym: 20plμs

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4.1 Final publishable summary report

- *Executive summary*

The reduction of cost per Watt-peak (W_p) for silicon solar cells is most efficiently achieved by reducing silicon material cost using thin wafers *and* by enhancing efficiency to above 20%. However today´s industrial standard cell structures are not suited to reach this goal. Additionally, the mechanical yield of the solar cell and module production has to be high enough to reach cost effectiveness, which tends to be in contradiction with wafer thickness reduction. The 20plµs project aimed to resolve this contradiction for a solar cell thickness of 100 µm at a solar cell conversion efficiency of above 20%.

The *overall objective* of this project was the development of a *20% efficient silicon solar cell* with a thickness *below 100 µm* and realizing a conversion efficiency of *19.5% on thin solar cells of a thickness of 100 µm with an area of 156 x 156* mm^2 in a pilot production line in the second half of the project duration. A process was developed and transferred to the ***industrial pilot production line*** of Hanwha Q CELLS. The result of the 100 µm thin cell fabrication is a ***median cell efficiency of 20%*** The best cell has an efficiency of 20.3 %. With process and handling adjustments a breakage rate of 4.5 % is achieved at the pilot line of Hanwha Q CELLS.

Cost and lifecycle analysis of the three process routes considered in the 20plµs project were carried out by ENI.

A dissemination work shop took place on Wednesday 24th of April at the Chambery Conference Centre Le Manage with the title "Industrially feasible processes for the next generation of high efficiency and thin crystalline silicon solar cells". This specific industry-oriented workshop was opened to the public and addressed the photovoltaic professionals. During the workshop the major 20plus EU-project results were presented. Also, external speakers were invited at the workshop.

- ***Summary description of project context and objectives***

The reduction of cost per Watt-peak (W_p) for silicon solar cells is most efficiently achieved by reducing silicon material cost using thin wafers *and* by enhancing efficiency to above 20%. However the industrial standard cell structures available at project start were not suited to reach this goal. Additionally, the mechanical yield of the solar cell and module production had to be high enough to reach cost effectiveness, which tends to be in contradiction with wafer thickness reduction. The 20plμs project aimed to resolve this contradiction for a solar cell thickness of 100 µm at a solar cell conversion efficiency of above 20%.

The *overall objective* of this project was the development of a *20% efficient silicon solar cell* with a thickness *below 100 µm*. The process was to be transferred to a *pilot line* at an industrial partner aiming at a yield that is comparable to the one in standard production and realizing a conversion efficiency of *19.5% on thin solar cells of a thickness of 100 µm with an area of 156 x 156 mm*^{2} in the second half of the project duration.

The project dealt with the full process flow, addressing the following topics which are particularly crucial for solar cells on thin wafers, in more detail: wafering, surface passivation, light trapping, solar cell and module processing and handling of the thin wafers.

Three basic process routes were followed which are categorized by the emitter formation temperature and the base material doping type i. e. p-type Si and n-type Si with high temperature - pht and nht - and n-type Si with low temperature emitter - nlt -. Schematics of these solar cell designs are given in Figure 1.

p-type high temperature **pht**	n-type high temperature **nht**	n-type low temperature **nlt**

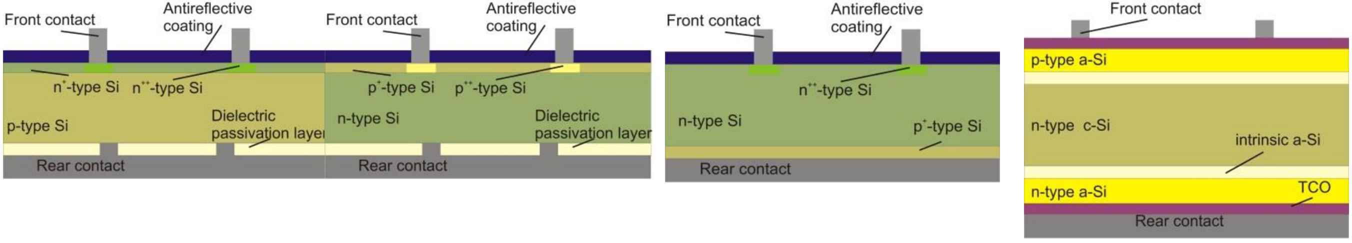

Figure 1: The general cell types developed within the project

The specific objectives of the project are explained in the following.

- The *wafering* of the Si ingots was performed by the established wire sawing process however using advanced technologies like diamond saw wires. The handling from the ingot to the process-ready wafer was investigated. The mechanical stability of the wafers was optimized applying different wet-chemical treatments. Breakage tests were carried out, assessing the impact of sawing and etching parameters on wafer strength. The target was to show a yield as high as that of standard wafering, but at lower thickness.
- When the wafers become thinner *surface passivation* becomes crucial, because more and more minority charge carriers reach a surface and their recombination needs to be reduced. Within the consortium, all passivation techniques currently under investigation within the PV

community were available. Therefore we aimed at the most suitable passivation layer with regard to deposition method and physical properties for each solar cell type according to Figure 1.

- Because of the indirect bandgap of Si, the part of the infrared light absorbed within the wavelength range of 900 to 1200 nm decreases with decreasing wafer thickness. The objective was to quantify and validate device structures allowing the best optical approaches for minimizing current losses, which are otherwise unavoidable because of the wafer thickness reduction. *Advanced light trapping schemes* were subsequently implemented into the solar cell concept.
- *Solar cell processes* according to Figure 1 were evaluated taking into account industrial feasibility and thus the time to bring the process into production as well as the efficiency potential. The evaluation was supported by the consortium's wide range of *characterization* methods. The main objective here was to find the best compromise between light trapping, surface passivation, emitter design, metallization, bulk lifetime, bulk resistance and handling. In particular, the selective emitter and the heteroemitter approach was to be investigated. Mechanically low-impact metallization techniques were evaluated like metal jet printing and plating. The solar cell process was adapted to different material qualities like those shown by mono- and multicrystalline Si wafers. In addition the further processing of the cells to modules was demonstrated.
- The *handling* of very thin and ultra-thin thin wafers shows some differences. While the 100 µm wafers can still be handled in an adapted standard way the wafers of a thickness of around 50 µm might need a support and are handled preferably horizontally. A feasible handling system for each category was to be defined and tested. A throughput of 1500 wafers/h for a handling step should be demonstrated.
- A step/iterative/comparative process in order to evaluate and describe the three new cell processes was followed to define a set of parameters needed to structure the life cycle analysis and cost model and to identify the most sustainable scenario from the technical-socio-environmental-economic point of view. The assessment included cost evaluations and scalability issues.

- ***Main S&T results***

In the following section the results of the project are presented in the context of work packages. The work was divided in 10 work packages along the solar cell process chain namely, WP1: Wafering and handling, WP2: Bulk properties, WP3: Emitter formation, WP4: Surface passivation, WP5: Light trapping structure, WP6: Metallization, WP7: Prototype cells, WP8: Integration of new processing steps into complete processes and fabrication of demonstration modules, WP9: Assessment and Dissemination. WP10 dealt with the project management.

Work package 1 "Wafering and Handling"

The activities of WP1 lay the foundation for the use of thin wafers in the following process sequences. The stability and yield of the subsequent process and handling steps depend on the wafer quality and the reduction of micro-cracks serving as starting points for cracks and thus wafer breakage. The development of a suitable cutting process including pre-processing of bricks with minimizing micro-crack formation and post-processing in form of wafer separation and wafer cleaning is the focus of the first two tasks within WP1. In most of the following steps of solar cell processing, the wafers are exposed to mechanical stress e.g. during printing, metallization and wet bench processing or thermal stress e.g. during diffusion or firing processes. The wafer manipulation between these steps represents a second type of load on the wafers. The adaption of these processes and a comprehensive optimization of wafer handling has also been worked on in WP1.

The actual industrial standard wafering process is optimized for the production of wafers with a thickness of 160 - 180 µm. To cut thinner wafers the pitch of the wire guidance rolls can easily be adjusted as a first step. However, the main challenge for cutting thin wafers below 100 µm thickness is a comparable wafer quality and yield. The experimentally cut wafers were characterised for thickness, roughness, sawing marks and partially for breaking behaviour.

Slurry sawn wafers typically show a wedge shape because the active silicon carbide (SiC) particle diameter dominating the material removal changes along the sawing channel due to breakage or drainage of the particles. The sawn wafer surface is dominated by brittle material removal which consists of stochastical indentations of SiC particles. In **Figure 2**, left, a three dimensional thickness mapping of such a wafer with a nominal thickness of 110 µm is shown.

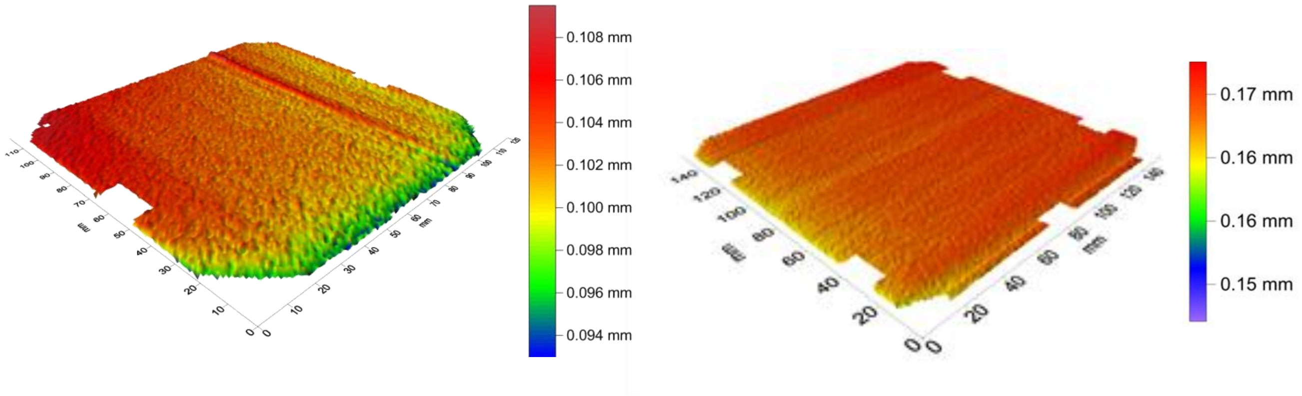

Figure 2: Left: Thickness mapping of an as cut 110 µm thick wafer using straight wire. Right: Example of the thickness mapping of a monocrystalline wafer cut with structured wire.

Wafer surfaces using structured wires show characteristic properties of diamond and straight wire sawn surfaces, compare to **Figure 2**, right. The surface structure suggests that a hybrid brittle-ductile material removal process is active when using structured wires. SiC particle indentations are visible without the typical wedge shape of standard slurry sawn wafers. Furthermore, the total thickness variation (TTV) values are reduced by about 50% for different combinations of wire velocity and feed rate which is especially essential for thin wafers. Therefore, a future task will be the process development for cutting of thin wafers by structured wire.

Work package 2 "Bulk properties"

The aim of the project is to develop high efficiency solar cell processes for mono- and multicrystalline Si. Therefore the selection of the most suitable material for each solar cell category as defined in Figure I has to be done for mono- as well as for multicrystalline Si. The evaluation of p-type versus n-type doping of the Si material is a key issue.

This WP is concerned with the evaluation of the doping type used with mono- or multicrystalline Si that is most suitable for the process transfer into the pilot production line as well as the achievement of highest efficiencies. In addition, the interaction between material properties and solar cell process was studied.

The 20plµs project dealt with mono and multicrystalline p-type Si and monocrystalline n-type Si, which was purchased for the consortium at the beginning of the project.

For the boron doped p-type mono-Si BO related degradation was investigated. A smaller V_{OC} degradation of 100 µm thin wafers compared to 180 µm thick wafers was determined for the thinner ones. 2dimensional simulation were carried out showing the dependence of the efficiency on doping concentration and wafer thickness. Thermal donors did not influence the properties of neither boron nor gallium doped Si.

The ELBA [1] method was applied to determine the material limited efficiency of the boron doped p-type Si material purchased. Spatially resolved efficiencies could have been determined. The boron doped monocrystalline Si material allowed to reach the final goal of 20% efficient 100 µm thick solar cells.

For n-type solar cells the optimum doping concentration for the PHOSTOP [2] cell concept was studied. The higher the base doping concentration, the smaller the optimal thickness of the Si substrate and the sharper the optimum, which the reduced diffusion length caused by an increased doping concentration accounts for.

For the low temperature approach the ideal wafer base resistivity was found to be between 1 and 5 Ωcm. Concerning the wafer thickness W, the passivation level can be maintained with the same a-Si:H layers by reducing W. But thanks to the reduction of W, the injection level corresponding to 1 sun is shifted to higher values. As a consequence, the implied V_{oc} of the cell precursor and also the real V_{oc} of the finished cell is increased.

All Si material purchased in the 20plµs underwent thorough process monitoring.

Work package 3 "Emitter formation"

This WP deals with the investigation of high temperature emitters in the advanced homogeneous emitter and the selective emitter design formed by high temperature diffusions from $POCl_3$ and BBr_3. The low temperature emitter is carried out as a heteroemitter based on amorphous Si. Besides the development of these processes each process is evaluated with regard to process complexity and efficiency potential.

The high temperature emitters were optimized with regard to a low emitter saturation current, the possibility to passivate them very well with industrially feasible means and to contact them with a low contact resistance.

Due to the kink and tail profile of the P-diffused Si a selective emitter etch back is a favorable way to reach lowly recombinative emitters. An etched back high temperature phosphorous emitter with less than 20 fA/cm^2 was demonstrated. A homogeneously diffused emitter without etch back showed a saturation current of less than 100 fA/cm^2.

For n-type Si wafer boron and aluminium emitters were investigated. Since the B emitter does not show a kink and tail, already as diffused emitter of 100 Ω/sq showed saturations currents below 20 fA/cm^2 on a planar surface passivated with Al_2O_3. The textured surface shows only a slightly enhanced saturation current of about 30 fA/cm^2. Contact resistivities of less than 2 mΩcm^2 and less than 4 mΩcm^2 for 50 and 100 Ω/sq high temperature boron emitters respectively were achieved with screen-printed paste.

Al doped emitters have been formed using Al-paste. The back junction solar cells showed a V_{OC} of 651 mV. The large bow of these solar cells was removed by applying the procedure from Huster [1=3] i.e. cooling the solar cell down to values well below 0°C and subsequently the cells are flat at room temperature.

The low temperature emitter based on amorphous Si is responsible on the solar cell front surface for significant parasitic absorption. The focus was put on the development of high quality passivation layers, giving high carrier lifetimes already in the as-deposited state and with minimal thicknesses. This allowed to achieve a V_{OC} of 747 mV determined on 97 µm thin nlt solar cell.

Work package 4 "Surface passivation"

The crystalline silicon wafers which are used as substrate for the fabrication of solar cells are almost perfect crystals. This perfection is giving to crystalline Si its incredible propriety that allows the conversion of suns light into electricity. However this perfection stops on the surface of the wafer, which gives to the surface very poor electrical properties. As the thickness of the substrate is decreasing the surface to bulk ratio increases and with it the effect of the surfaces. In order to fabricate high efficiency Si solar cells a very good surface passivation is needed, this is true for thick solar cells but even more crucial for very thin wafers. In this project, several types of passivation layers were developed:

- a-Si passivation layers were developed for the fabrication of heterojunction solar cell (nlt). These layers provide a very high passivation quality allowing surface recombination velocity bellow 10 cm s^{-1}. A deposition method known as “layer by layer deposition” was used in order to achieve the highest passivation quality while keeping the film thickness very low (< 10 nm). The excellent passivation quality allowed to obtain V_{oc} up to 747 mV on very thin wafers.
- For *p*-type wafers processed at high temperature (pht), the front surface passivation used was SiO_2 SiN_x stacks or simply a SiN_x layer. The rear surface passivation was provided by Al_2O_3 SiN_x stack, which is an excellent passivation solution for lowly doped *p*-type surfaces. These layers could provide a passivation quality allowing surface recombination velocity bellow 10 cm s^{-1} even after a fast high temperature contact sintering (firing) which is perform at a temperature above 800°C for a few seconds. A great focus was put on a deposition method that allows the pilot line production of solar cells. The Al_2O_3 layers were deposited using an inline PECVD system. The process on this tool was shown to be homogenous and repeatable. For this solar cell concept, a solar cell efficiency of 19.9% was obtained on 103 µm thin wafer, with a V_{oc} of 672 mV. The internal quantum efficiency’s (IQE) shape testify the very high rear passivation quality.
- For *n*-type wafers processed at high temperature (nht), the surface passivation of the *n*-type doped surface (front or back surface field) was realised by SiO_2/SiN_x stacks or a simple SiN_x layer. The boron emitter was passivated by Al_2O_3 SiN_x stack, which provides a very high passivation quality. Very low emitter saturation current density of about 36 fA/cm^2 was reach on a 90 Ω/sq. emitter. It was calculated, that this value corresponds to a surface recombination velocity of about 340 ± 20 cm s^{-1} for a surface doping concentration of 7×10^{19} cm^{-3} which is more than one order of magnitude lower than for SiO_2. It is important to point out that this excellent result was not only obtained only for ALD Al_2O_3 layers but also for PECVD Al_2O_3 layers, which can be used in a pilot production line.

The passivation of the surface is very important however it cannot be developed independently from the other solar cell processes and requirement. The surface passivation is usually obtained by depositing a layer on the surface of the wafer or by growing a SiO_2 layer, which affect the optics of the solar cell. Therefore the development of the passivation layer needs to be done in line with the light trapping. Here the focus was put on the rear internal reflection properties provided by rear passivation stacks. It was obtained that the stacks composed of a thin Al_2O_3 layer covered by a SiN_x layer can provide a rear internal reflectance of 90%, without compromising the passivation quality or the possibility of forming a contact.

The post-passivation steps should be also taken into account in the development of the passivation concept. More especially during the metallisation step, in the case of Ni plating in the front contact, the front dielectrics is playing the role of a masking layer. As Ni deposit on all non-covered Si surfaces the front surface passivation need to be very dense. Here the best results were obtained using LPCVD SiN_x. The metallisation often mean also, a high temperature step that might destroy the passivation quality. For this reason, the Al_2O_3 SiN_x passivation solution was developed to be resistant to firing process, and was also found to resist against attacks of Al during firing processes.

During the project a passivation competition was organised between four partners. As shown in Figure 3 all the partners went very close and all of them obtained a lifetime ranging 2 ms on a *p*-type 1 Ωcm FZ-Si substrate. In other words, an excellent passivation quality was obtained by the four participants.

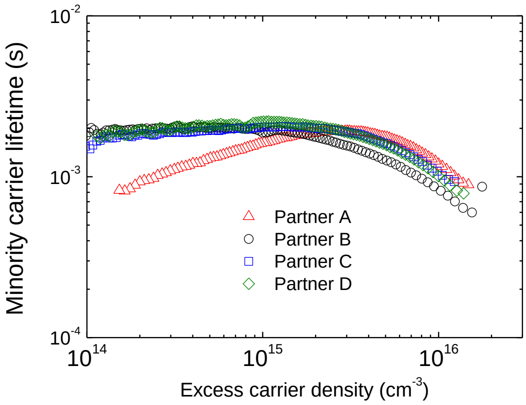

Figure 3: Minority carrier lifetime as a function of the excess carrier density.

Work package 5 "Light trapping structure"

The overall objective of WP05 is to maintain high short-circuit current (J_{sc}) as the wafer thickness is decreased to less than 100 µm. WP05 is broken into three tasks, and we present here summaries of the results of each task.

Task 5.1 was concerned with the development and assessment of new materials and material stacks with superior optical performance. Much of the work within this task was focused on the rear reflector materials stack, since it is a significant source of parasitic absorption in all three cell types (pht, nht, and nlt). For high-temperature cells, silicon oxide/silicon nitride/aluminum (SiO_2/SiN_x/Al) and aluminum oxide (Al_2O_3)/SiN_x/Al reflectors were investigated experimentally and theoretically as a function of the dielectric layer thicknesses, and reflectances above 90% were achieved at 1200 nm for optimized stacks on wafers with polished front surfaces, indicating low parasitic absorption. For nlt solar cells, a new, high-mobility transparent conductive oxide (TCO) material—hydrogenated indium oxide—was developed and demonstrated to increase long-wavelength quantum efficiency—and thus J_{sc}—because of its reduced free-carrier absorption [3]. In addition, a thorough analysis of the parasitic absorption in the front TCO/amorphous silicon (a-Si) stack of nlt solar cells (these layers and their associated absorption are absent in nht and pht cells) was performed experimentally with complementary modelling [4]. Optimization of the a-Si layer thicknesses and TCO allowed us to achieve a 2 mA/cm^2 gain in J_{sc}. Also, starting with the external quantum efficiency (EQE) and reflectance (R) spectra measured on our best 100-µm-thick nlt cell, we showed several ways in which these spectra may be modified to boost $J_{sc,active}$ to 41 mA/cm^2. The three possible routes to improvement are decreased UV parasitic absorption, improved internal reflection, and improved light trapping. We showed that the first route is the most effective and that extending the path length of IR light is not the only way to high currents.

Task 5.2 focused on assessing the effects of various light trapping schemes, and in particular, examining the role of surface texture. For monocrystalline wafers, a side-by-side comparison was performed for alkaline (pyramids), acidic (craters), and plasma (nanostructures) textures. With an Al_2O_3/SiN_x/Al rear reflector stack developed in Task 5.1, we demonstrated that the surface texture greatly influences the long-wavelength reflection (and therefore J_{sc}), indicating that either the front reflectance or parasitic absorption in the Al layer may be sensitive to texture [5]. For multicrystalline Si wafers, a honeycomb texture achieved by mass-production-compatible nano-imprint lithography was developed. Tests on wafers of various thicknesses resulted in no breakage for wafers as thin as 100 µm, and the new honeycomb texture often outperformed the standard multicrystalline acidic “isotexture” in reflectance measurements. We reported that IR parasitic absorption in silicon heterojunction solar cells arises from free-carrier absorption in both the front and rear TCO layers, as well as plasmonic absorption in the rear metal electrode [6,7]. The plasmonic loss occurs only for p-polarized light that is incident on the rear TCO above the critical angle, and only if the metal electrode is within the penetration depth of the resulting evanescent wave. Consequently, one method to mitigate the loss in the metal electrode is to require the rear TCO layer to play an optical as well as electrical role by making it thick and very transparent. An alternative approach is to make the rear TCO very thin so that it serves only an electrical contact function (or dispose of it altogether if a suitable doped a-Si:H/metal junction can be formed), and to add another layer specifically to suppress plasmon excitation in the metal electrode. An MgF_2/Ag reflector was demonstrated to yield an average rear internal reflectance of greater than 99.5% and an infrared internal quantum efficiency that exceeds that of the world-record UNSW PERL cell [8]. Local contacts through the insulating MgF_2 layer are necessary to collect electrons at the rear of the cell. However, the contact design requirements are relaxed compared to those for PERL-like solar cells because these local contacts are through an optical—not passivation—layer. With such as rear structure an active area short circuit current density > 42 mA.cm^{-2} is feasible for nlt-type cells.

The goal of *Task 5.3* was to evaluate the impact on device performance of the new materials and light-trapping schemes developed in Tasks 5.1 and 5.2. This analysis has both experimental and theoretical components: EQE and reflectance measurements are used to evaluate the gains and losses in J_{sc} as new materials, stacks, and textures are developed and integrated, while modelling is employed to predict the performance of new structures in final devices. A rigorous coupled wave analysis (RCWA) optical simulation of a cell with a SiO_2 rear diffraction grating was carried out for variable grating period and depth. For a textured front surface, a J_{sc} gain of 0.2–0.7 mA/cm^2 is predicted for an optimized grating compared to a planar rear surface. For nlt cells, we have performed a complete experimental analysis of all J_{SC} losses in a high-efficiency (>20%) cell 96 µm thick. Active-area and aperture-area J_{SC} were measured and compared to reveal that 6% of light is reflected from the front silver grid, corresponding to a J_{SC} loss of 2.2 mA/cm^2. EQE and reflection measurements showed that 1.1 mA/cm^2 is lost because of reflection from the front wafer surface, 1.5 mA/cm^2 remains to be gained by eliminating parasitic absorption in the front a-Si layers, 1.1 mA/cm^2 is lost because of parasitic absorption in the TCO and rear metal reflector, and 0.6 mA/cm^2 can be gained by improving light trapping. This analysis provides a clear path to further improvement of J_{SC} in thin nlt cells, as required by WP05.

Besides, losses of maximum 2 mA/cm^2 on 70 µm thick nlt cells compared to standard thickness were demonstrated. Table 1 compares nlt solar cells made from wafers with different thicknesses, but the same a-Si:H layers and TCOs have been used on both devices. We see that even with a drastic reduction of wafer thickness down to 70 micron, we still can maintain a high short circuit current density, where a J_{sc} loss < 2mA/cm^2 is achieved.

	FZ **250 µm** **4 cm^2**	**Cz** **70 µm** **4 cm^2**
V_{oc} [mV]	726	747
J_{sc} [mA/cm^2]	38.1	36.9
FF [%]	77.0	77.9
Efficiency [%]	22.3	21.5

Table 1: Solar cell characteristics of a 70 µm-thick wafer compared to standard 250 µm-thick device.

Work package 6 "Metallization"

The metallization of very thin and ultra-thin Si wafers requires careful selection of an appropriate metallization process. The compatibility of the metallization process with the properties of the surface passivation layer must be considered. Owing to the difference between the thermal expansion coefficients of the metal and Si, the mechanical impact of the metallization must also be taken into account.

The key ***objectives of WP06*** were to develop non-contact and/or low temperature technologies to avoid thermal and mechanical stresses on thin wafers, to minimize current losses due to shading by employing front contact finger widths ≤ 50 µm, and to minimise series resistance through the optimization of contact geometry and the use of advanced metallization technologies capable of achieving line resistance ≤ 0.3 Ω/cm and contact resistivity values ≤ 2 mΩ/cm^2.

The output from this WP resulted in several scientific achievements and the successful delivery of key deliverables and milestones. Front contacts less than 50 µm (35 µm) wide were produced with gridline resistance of less than 0.3 Ω/cm (0.21 Ω/cm). A robust two-step Ni plating process electroplated with Cu was achieved resulting in line resistance < 0.3 Ω/cm and linewidth ~ 65 µm.

A 100µm thick LGBC/LFC solar cell demonstrating increased IQE at longer wavelengths was demonstrated. However, LGBC were not recommend for the processing of 100µm thick cells, since LGBC front contacts compromised the mechanical stability of the wafer. A process combining aerosol jet printing and LIP has been demonstrated on standard thickness cells resulting in efficiencies of 20.3 % on 4 cm^2. A metallisation process combining electroless Ni and Cu LIP has also been developed. Screen printing with low temperature paste has been successfully demonstrated on 96 µm n-type low temperature (nlt) process cells (Efficiencies of 20.8 % on 4 cm^2). A gain of over 3 mA/cm^2 was demonstrated by improved light confinement for 100 µm on nlt cells. Finally, a 20.3% efficient 100µm thick screen printed solar cells were demonstrated on a pilot production line facility.

Work package 7 "Prototype cells"

Prototype solar cells integrating the individual processing steps from work packages 1 to 6 are developed in this WP.

Starting the development on 100 µm thin p-type boron doped Cz-Si solar cell full area screen-printing was applied forming the BSF and the base contact. On the front a selective emitter was applied which was passivated by an oxide nitride stack. With this concept an efficiency of 18.7% with a V_{OC} of 645 mV, a J_{SC} of 36.6 mA/cm^2 and a FF of 79.3% was achieved.

After optimising front emitter and rear local contact properties an independently confirmed efficiency of 19.9 % for the best thin PERC solar cell, fabricated on 0.5 Ωcm boron-doped p-type silicon material was demonstrated. The other cell parameters are a high V_{OC} of 672 mV, a J_{SC} of 38.5 mA/cm^2 and a FF of 76.8%. An area-averaged cell thickness of 103 µm was determined via weight measurement. This cell concept has been realised without any alignment steps during manufacturing.

A first set of 100 µm thin mc-Si solar cells with dielectric rear passivation and laser fired Al contacts were manufactured. The front emitter on an acidic texture was passivated by a SiN layer and the base at the back by a stack of Al_2O_3 and SiN. Front contacts were silver screen-printed and the rear metal was evaporated on the full area. Rear contacts were formed by the LFC method. An efficiency of 16.9% was achieved. The other cell parameters are a high V_{OC} of 625 mV, a J_{SC} of 35.4 mA/cm^2 and a FF of 76.2%. A second set of mc-Si solar cells showed efficiencies up to 17.1%. The efficiencies were mainly limited by the bulk lifetime of the Si wafer.

Using thin n-type Si wafers, Al rear emitter solar cells of 100 µm with homogeneous and selective emitter were fabricated. The Al emitter was full area contacted by the Al metal paste. The front surface field was passivated by a stack of thermal oxide and SiN. The cell had a size of 125 x 125 mm^2, the base resistivity was 2.8 Ωcm. The solar cells with selective FSF achieved efficiencies of up to η = 19.0% compared to the homogeneous FSF samples with η = 18.0%.
Applying the low temperature emitter to fabricate a Si heterojunction solar cell an only 70 µm thin cell with an efficiency of 21.7% was demonstrated. The V_{OC} was as high as 747 mV and the J_{SC} and FF were at 37.5 mA/cm^2 and 77.8% respectively.

Work package 8 "Integration of new processing steps into complete processes and fabrication of demonstration modules"

The objective is the transfer of the developed processes to an industrial-type setting and demonstration of pilot production of very thin cells (100 µm thick) at an efficiency of 19.5% on 156 x 156 mm² large area wafers and manufacturing of a demonstration module. WP8 assembles the suggested preferred processes for each step from WP1 to 7.
The decision for the solar cell process for the pilot production line is made in MS30 as the starting point for transfer of the process from research lab-type setting to an industrial-type setting. The pht process with the additional processing steps rear passivation and LFC compared to the standard screen printed reference process is the less complex process to realize. The nht process is chosen as a backup in MS30. It has a higher efficiency potential than pht but a more complex development is required. A nlt process has the highest efficiency potential, but is the least developed technology. Therefore the development timeline in an industrial-type setting at HQC of a nlt process was too long for the scope of the project.

Nht (*n*-type high temperature)
Single side alkaline texture
BBr3 diffusion
BSG removal
Front ARC
Single side emitter removal
POCl3 diffusion rear
PSG removal
PECVD SiN rear
Front contacts screen-printing Ag/Al
Drying
Firing in a belt furnace
Laser opening of SiN
Physical vapor deposition of Al

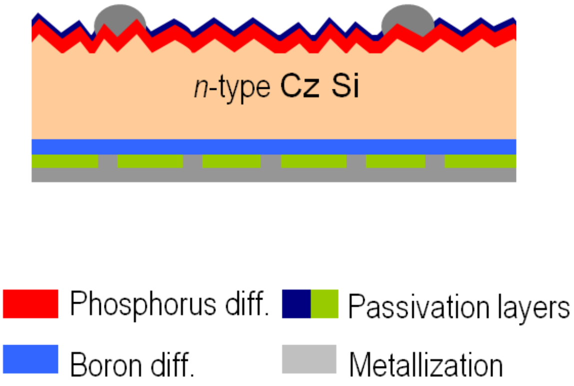

Figure 4: Baseline process for mono-crystalline n-type Si front junction solar cells of the high temperature route, suggested by the project (left). A double-side contacted back junction solar cell is the modified nht cell for HQC pilot line production (right).

In D08.1 the cell processes from WP1 to WP7 are integrated into complete pilot line high efficiency cell processes of pht and nht. Large area cells with 200 µm thickness are fabricated to prove the feasibility of the process routes. Nht showed higher cell efficiencies than pht. In a first fabrication lot the nht route of Figure 4 left achieved a median cell efficiency of 19.7 %. Process flow was still with additional thermal SiO_2 as diffusion barriers, to make sure that both diffusions are separated. To adapt cells to feasible mass production the nht route is then modified in D08.2 to a back junction cell route [9]. With this modified nht route a complete ingot can be used [10]. The n-type ingot distribution is industrially feasible for ingots > 5 Ωcm. From 2 to 5 Ωcm: the passivation quality of the front side n^+-n junction improves with increasing bulk resistivity [11], therefore J_{sc} and η increase strongly. Efficiencies up to 20.9 % (5.1 W) on 6” back junction cells are reached after further improvement of passivation and metallization.

For saving Si material the influence of wafer thickness is estimated by PC1D simulation in D08.2 (Figure 5 left) [12, 13]. The outcome of the simulation is: the back junction cell concept is suitable for 100 to 200 µm thick wafers. There is freedom of choice, adaption to wafer market situation is possible.

In D8.3 the high efficiency cells of the pilot line are successfully integrated into a 60 cell module produced with modified nht from 200 µm thick wafers. With cells of 19.6 to 20 % cell efficiency a module of 278 W is produced.

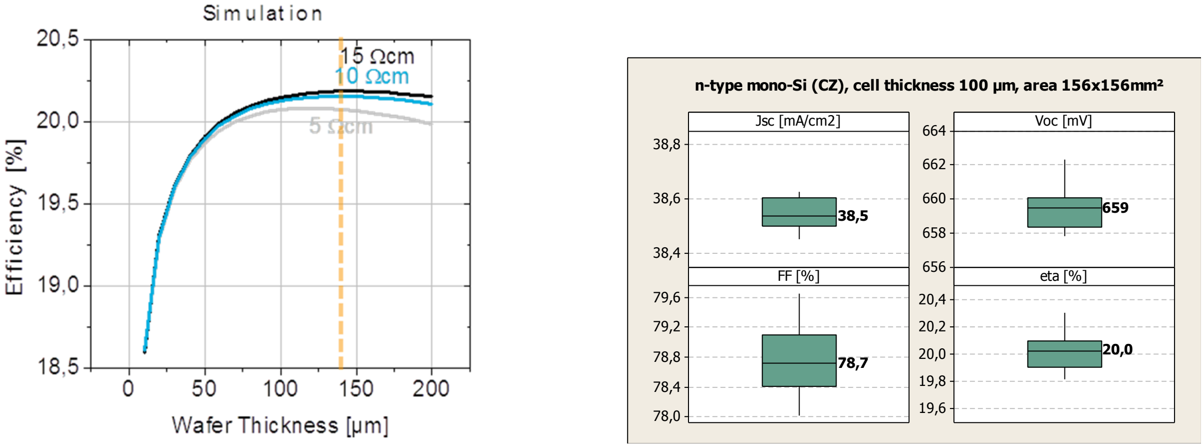

Figure 5: Left: simulated influence of wafer thickness on back junction solar cell. Cell concept is suitable for 100 to 200 µm thick wafers. Right: result of 100 µm thin cell fabrication is a median cell efficiency of 20 %.

Finally in D08.5, D08.6 and MS37, the high efficiency process steps of D08.2 and handling are adjusted to thin wafers to arrive at the project goal of a high efficiency cell production with thin wafers with total breakage rates < 5 %. Diamond wire sawn wafers are used, because of their better total thickness variation compared to slurry sawn wafers. The metallization process generates most mechanical stress and bowing of wafers. Therefore the bus bars are printed rectangular to the sawing grooves taking advantage of the higher stability of diamond wire sawn wafers rectangular to the sawing grooves. Completely processed solar cells with thickness of 100 µm show a 3 mm bow. During transfer of wafers from carrier to belt the thin wafers with bow stick together. To avoid this, the carrier height has to be corrected. Furthermore, drying air stream after printing, firing temperature, and soldering conditions are adjusted to the thin cells. With process and handling adjustments a breakage rate of 4.5 % is achieved, tested with 100 µm thin cells processed with modified nht at the pilot line of Hanwha Q CELLS. The simulated influence of wafer thickness is confirmed by the fabricated cells of 100 µm thickness. Thinner cells show a current loss, which fits to an IQE loss for long wavelengths. The result of the 100 µm thin cell fabrication is a median cell efficiency of 20 % (Figure 2 right). The best cell has an efficiency of 20.3 %. With this result D08.6 and the project goal of 19.5 % cell production efficiency of 100 µm thin, 156 x 156 mm² large area cells is successfully demonstrated in the pilot line of Hanwha Q CELLS.

Work package 9 "Assessment and Dissemination"

Work Package 9 takes into account assessment and dissemination activities. Three different process cells are proposed within the project and referred to as pht, nht and nlt routes. Each of those is an industrial feasible process targeted to achieve high cell efficiencies on thin wafers.

The assessment phase consisted of comparing the process flows to establish the maturity of each technology and its relating readiness for a pilot line production transfer. The evaluation was not limited at the scaling up angle, but focused to take into account potentiality of each technologies with spotlight on beneficial/detrimental aspects. In this regard, environmental impacts were assessed and manufacturing costs calculated.

The dissemination activity consisted of organizing a dissemination workshop, focused on presenting the major results achieved during the project.

Assessment phase

Process scale-up

The first decisional aspect involved the transfer of the processes from lab scale to pilot line production. Particular attention was paid to the following issues: efficiency potential, availability of industrial equipment, process complexity, process compatibility with thin substrates (induced mechanical stresses), module integration, intellectual properties and possible additional processing costs. The pht route was found to be the most feasible process for pilot line production implementation; the nht route was kept as alternative backup process.

Cost analysis

The cost analysis consisted of calculating the Cost of Ownership (CoO) for all the three 20plµs processes (pht, nht and nlt). It was developed in three stages.

In the CoO calculation the following expenses were considered: operating costs (supply of raw materials, utilities and consumable parts), as well as construction of the buildings (e.g. for production, offices...), equipment purchase, facility/utility/storage, labour, maintenance and quality loss (mechanical, optical and electrical yield losses) costs.

Wafers were supposed to be purchased.

In the first two stages, the CoO was calculated for a cell fab located in the EU and with 60 MWp yearly capacity and 20plµs routes were compared one with the other. The pht route turned out to be the most cost effective technology.

In the third stage, the CoO was calculated for mass production in Asia of pht cells. Costs were calculated assuming economy of scale. A comparison with the reference process was carried out. It turned out that the pht route could achieve a total cost reduction in the range of 24-28%, such range depending on process yield optimization.

Life Cycle Assessment

Environmental performances of 20plµs processes were calculated by means of LCA analysis. The EDIP methodology was applied to assess the impacts. The analysis is carried out in three different steps.

In the first calculation, the analysis was focused on cell manufacturing, neglecting treatment of waste waters. In the second calculation, data was refined and waste water treatment was included in the simulation. It turned out that PECVD and metallization steps play a relevant role in the impacts. As for PECVD, the exhaust gases require appropriate cleaning, with resulting negative effect on impacts due especially to fossil fuel use in the cleaning process. Also metallization represents a critical process, independently of the specific technology used to apply the electrodes onto the cells. Impacts are caused by precious metals use.

In the third run, data was further refined and system boundaries were extended to include the production of thin wafers. Impacts of 20plµs routes were compared with reference technology (for the reference process, the production of c-Si wafers with standard thickness was considered). It was found that, category by category, significant improvements can be reached when thin wafers are used. In fact, impacts related to 20plµs routes are always lower than the reference’s ones, with the exception of photochemical oxidation.

Additionally, systems boundaries were extended to include also the assembly of cells into modules, BOS and installation of PV-systems on rooftop. Carbon Footprint and Energy PayBack Time, which are typical environmental performance indicators of PV-systems, were calculated for 20plus-technology applying PV-systems and compared with those of the reference case. A significant drop-down in Carbon Footprint and EPBT values was found for 20plus PV-systems.

Dissemination

The "20plus Dissemination Workshop" took place on Wednesday 24th of April at the Chambery Conference Centre Le Manage with the title "Industrially feasible processes for the next generation of high efficiency and thin crystalline silicon solar cells". This specific industry-oriented workshop was opened to the public and addressed the photovoltaic professionals. During the workshop the major 20plus EU-project results were presented. Also, external speakers were invited at the workshop.

Work package 10 "Project management"

All project management was organized in this work package. UKON was responsible for the overall coordination. PSE provided support for administrative management tasks.

The main ***objectives*** were:

- Enable a smooth flow of the project
- Ensure well timed reporting to the European Commission

Results:

Day-to-day management of the project
Management of Deliverables and Milestones
Meetings organized
Minutes drafted and completed
Website updated
Intellectual Property Rights management
Amendment to the contract implemented when there were changes in the Consortium (three major changes at the consortium partners in three years)
Financial management: Collection and compilation of cost details and justifications
Periodic and final reporting done

- ***Potential impact and the main dissemination activities and exploitation of results S&T results***

Within the 20plus project significant attention was paid to socio-environmental-economic aspects.

First of all the 20plµs technology was analyzed from the technological point of view and the scalability to pilot line production was assessed. All the aspects can act as driving force in the lowering of the PV-generated kWh cost and ultimately target the spread out of PV-systems to reach a broader distributed electricity generation scenario in the EU.

On the environmental side, a life cycle analysis was performed to assess the sustainability of the 20plµs technology. From the environmental point of view, it was found that lower impacts, lower values of embodied energy and shorter energy payback times can be achieved if 20plµs technology-based PV-systems are installed.

Therefore, PV-systems applying the 20plµs technology are more environmentally sustainable than the ones applying the present industrial reference technology.

The observed beneficial effects on costs and environmental performances are only possible with a combination of cells with high efficiency and wafers with reduced thickness. Therefore, the development of industrial tools able to manufacture efficiently large volumes of 100 µm thick wafers plays a key role on the market entry and success of 20plµs cells.

At the German site, Hanwha Q CELLS operates the Reiner-Lemoine Research Centre, including a pilot line for cell processing and a sophisticated characterization laboratory. In the R&D centre all production relevant equipment is available for all kind of cell c-Si processing. Located next to it HQC operates a production line with a cell capacity of 200 MWp. Developed new solar cell concepts and technologies can be scaled-up fast from research level to mass- production. With this setup HQC was eligible to participate in the project as industrial partner and care for the exploitation of the project outcomes.

The demonstration of pilot-production of new cell concepts within the Research Line has the following goals:
- qualification
- proof of manufacturing capability
- optimization of cell concepts and corresponding production processes

The priorities of pilot line operation are:
- Fast transfer and realization of innovations
- Base-line production of innovations for yield and process learning

In the 20plµs project, 20% efficiency was achieved in the pilot line on 100 µm thick industrially feasible c-Si solar cells. The influence of wafer thickness on the cell performance was simulated. It showed that the 20plµs pilot line cell concept is suitable for 100 to 200 µm thick wafers.

The know how generated for the handling of thin Si wafers with a high throughput and high yield is ready for use in industrial handling systems.

The "20plus Dissemination Workshop" took place on Wednesday 24th of April at the Chambery Conference Centre Le Manage with the title "Industrially feasible processes for the next generation of high efficiency and thin crystalline silicon solar cells". This specific industry-oriented workshop was opened to the public and addressed the photovoltaic professionals. During the workshop the major 20plus EU-project results were presented. Also, external speakers were invited at the workshop.
Several scientific publications have been disseminated as listed below in section 4.2.

- **Public website**: www.20plus-pv.eu

References:

[1] B. Michl, M. Rüdiger, J. Giesecke, M. Hermle, W. Warta, M.C. Schubert, Solar Energy Materials & Solar Cells, 98 (2012) 441-447
[2] Meier DL, Davis HP, Garcia RA, Salami J, Rohatgi A, Ebong A, Doshi P. Aluminum alloy back p-n junction dendritic web silicon solar cell. *Sol En Mat & Solar Cells* 2001;**65**:621-7
[3] L. Barraud, Z. Holman, P. Reiss, A. Descoeudres, C Battaglia, S. De Wolf, and C. Ballif, *Hydrogen-doped indium oxide/indium tin oxide bilayers for high-efficiency silicon heterojunction solar cells,* Sol. Energy Mater. Sol. Cells **115**, 151 (2013).
[4] Z.C. Holman, A. Descoeudres, L. Barraud, F. Zicarelli, J. Seif, S. De Wolf, and C. Ballif, *Current losses at the front of silicon heterojunction solar cells,* IEEE J. Photovoltaics **2**, 7 (2012).
[5] Z.C. Holman, M. Filipič, B. Lipovšek, S. De Wolf, F. Smole, M. Topič, and C. Ballif, *Parasitic absorption in the rear reflector of a silicon solar cell: Simulation and measurement of the sub-bandgap reflectance for common dielectric/metal reflectors,* Sol. Energy Mater. Sol. Cells **117**, 426 (2014).
[6] Z.C. Holman, S. De Wolf, and C. Ballif, *Improving metal reflectors by suppressing surface plasmon polaritons: A priori calculation of the internal reflectance of a solar cell,* Light: Science & Applications **2**, e106 (2013).
[7] Z.C. Holman, M. Filipič, A. Descoeudres, S. De Wolf, F. Smole, M. Topič, and C. Ballif, *Long wavelength light management in high-efficiency silicon heterojunction solar cells,* J. Appl. Phys. **113**, 013107 (2013).
[8] Z.C. Holman, A. Descoeudres, S. De Wolf, and C. Ballif, *Record Infrared Internal Quantum Efficiency in Silicon Heterojunction Solar Cells with Dielectric/Metal Rear Reflectors,* IEEE J. Photovoltaics **3**, 1243 (2013).
[9] T. Ballmann et al., 2nd nPV workshop, (2012).
[10] V. Mertens et al., Proc. 2nd Silicon PV Conference, (2012).
[11] M. Hermle et al., J. Appl. Phys., 103, 054507, (2008).
[12] T. Buck et al., Proc. 19th EUPVSEC, pp. 1255-1258, (2004).
[13] H. Nagel et al., Proc. 21st EUPVSEC, pp. 1228-1234, (2006).

4.2 Use and dissemination of foreground

In this chapter a plan for use and dissemination of foreground (including socio-economic impact and target groups for the results of the research) can be found.

The plan consists of:

- Section A

  This section describes the dissemination measures, including any scientific publications relating to foreground. **Its content will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

- Section B

  This section specifies the exploitable foreground and provides the plans for exploitation. Information under Section B that is not marked as confidential **will be made available in the public domain** thus demonstrating the added-value and positive impact of the project on the European Union.

Section A (public)

The following tables A1 and A2 reflect the dissemination activities in 20plus for the whole duration of the project.

Table A1: : List of all scientific (peer reviewed) publications relating to the foreground of the project.

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[1] (if available)	Is/Will open access[2] provided to this publication?
1	*Improved amorphous/crystalline silicon interface passivation by hydrogen plasma treatment*	*A. Descoeudres*	*Appl. Phys. Lett.*	*No 99, 2011*	*n.a.*	*n.a.*	*2011*	*n.a.*	*doi:10.1063/1.3641899*	*yes/no*
2	*High-temperature stability of c-Si surface passivation by thick PECVD Al2O3 with and without hydrogenated capping layers*	*P. Saint-Cast*	*Applied Surface Science*	*2010*					*doi:10.1016/j.apsusc.2012.03.171*	
3	*Variation of the layer thickness to study the electrical property of PECVD Al2O3 / c-Si interface*	*P. Saint-Cast*	*Energy Procedia*	*8 (2011)*	*Elsevier*		*2011*	*642–647*		
4	*High-efficiency Silicon*	*S. De Wolf*	*Green*	*Vol. 2 (2012)*			*2012*	*7–24*		

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[1] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[2] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	Heterojunction Solar Cells: A Review									
5	*Very fast light-induced degradation of a-Si:H/c-Si(100) interfaces*	*S. De Wolf*	*Physical Review*	*B 83 (2011)*			*2011*			
6	*Kinetics of a-Si:H bulk defect and a-Si:H/c-Si interface-state reduction*	*S. De Wolf*	*Physical Review*	*B 85 (2012)*	*APS*		*2012*			
7	*Improved amorphous/crystalline silicon interface passivation by hydrogen plasma treatment*	*A. Descoeudres*	*Applied Physics Letters*	*99, 123506 (2011)*			*2011*			
8	*Current Losses at the Front of Silicon Heterojunction Solar Cells*	*Z. C. Holman*	*IEEE Journal of Photovoltaics*	*VOL. 2, NO. 1, January 2012*			*2012*			
9	*Screen-Printed Al-Alloyed Rear Junction Solar Cell Concept Applied to Very Thin (100 µm) Large-Area n-Type Si Wafers*	*Y. Schiele*	*Energy Procedia*	*27 (2012)*	*Elsevier*		*2012*	*460–466*	*doi: 10.1016/j.egypro.2012.07.094*	*Yes*
10	*SiliconPV Abstract Yvonne*	*Y. Schiele*	*Energy Procedia (2014) (submitted)*	*2014*						
11	*Parasitic absorption in the rear reflector of a silicon solar cell: Simulation and measurement of the sub-bandgap reflectance for common dielectric/metal reflectors*	*Z.C. Holman*	*Sol. Energy Mater. Sol. Cells*	*117, 2014*	*Elsevier*		*2014*			
12	*Scanning Laser Beam Induced Current Measurements of Lateral Transport near Junction Defects in Silicon Heterojunction Solar Cells*	*M.G. Deceglie*	*IEEE J. Photovoltaics*	*2013*	*IEEE EDS*		*2013*			*no*
13	*Analysis of lateral transport through inversion layer in a-Si:H / c-Si solar cells*	*M. Filipič*	*J. Appl. Phys*	*114, 2013*	*AIP*		*2013*	*074504*		*no*
14	*Record Infrared Internal*	*Z.C. Holman*	*IEEE J.*	*3, 2013*	*IEEE EDS*		*2013*	*1243*		*no*

	Quantum Efficiency in Silicon Heterojunction Solar Cells with Dielectric/Metal Rear Reflectors		*Photovoltaics*							
15	*Improving metal reflectors by suppressing surface plasmon polaritons: A priori calculation of the internal reflectance of a solar cell*	*Z.C. Holman*	*Light: Science & Applications*	*2, 2013*			*2013*	*E106*		
16	*Amorphous / crystalline silicon interface defects induced by hydrogen plasma treatments*	*J. Geissbuehler*	*Appl. Phys. Lett*	*102, 2013*	*AIP*		*2013*	*231604*		*no*
17	*Hydrogen-doped indium oxide/indium tin oxide bilayers for high-efficiency silicon heterojunction solar cells*	*L. Barraud*	*Sol. Energy Mater. Sol. Cells*	*115, 2013*	*Elsevier*		*2013*	*151*		*no*
18	*Long wavelength light management in high-efficiency silicon heterojunction solar cells*	*Z.C. Holman*	*J. Appl. Phys*	*113, 2013*	*AIP*		*2013*	*013107*		*no*
19	*Silicon heterojunction solar cells on n- and p-type wafers compared*	*A. Descoeudres*	*IEEE J. Photovoltaics*	*3, 2013*	*IEEE EDS*		*2013*	*83*		*no*
20	*Damage at the a-Si:H / c-Si interface by indium tin oxide overlayer sputtering*	*B. Demaurex*	*Appl. Phys. Lett*	*101, 2012*	*AIP*		*2012*	*171604*		*no*
21	*ENVIRONMENTAL SUSTAINABILITY OF HIGH EFFICIENT 100 µm THICK C-SI SOLAR CELLS*	*F.S Grasso*	*Proceedings of the 28th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC) in Paris (2013)*				*2013*			*no*
22	*Development of rear passivated laser grooved buried contact (LGBC) laser fired contact*	*D. Morrison*	*Proceedings of the 27th European*				*2012*			*no*

	(LFC) silicon solar cells using thin wafers		*Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC) in Frankfurt (2012)*							
23	*Silicon heterojunction solar cells on n- and p-type wafers with efficiencies above 20%*	*A. Descoeudres*	*27th EUPVSEC, Frankfurt, Germany*	*2012*			*2012*			*no*
24	*Investigation of wafer breakage and wafer quality for thin slurry sawn wafers*	*B. Weber*	*6th Proceedings of the International Workshop on Science and Technology of Crystalline Silicon Solar Cells*	*October 8-11, 2012*	*n.a.*	*n.a.*	*2012*	*4*		
25	*CHALLENGES OF THE MULTI WIRE SAWING PROCESS FOR THIN WAFERS BELOW 120 µm THICKNESS*	*B. Weber*	*Proceedings of the international conference held in Frankfurt, Germany*	*24 - 28 September 2012*	*WIP-Renewable Energies, 2012*	*n.a.*	*2012*	*pp.1060-1063*	*DOI: 10.4229/27thEUPVSEC2012-2AV.4.50*	*yes*
26	*DRAHTSÄGEPROZESSENTWICKLUNG FÜR DIE WAFERHERSTELLUNG*	*B. Weber*	*Annual Report*	*2011*	*Fraunhofer ISE*	*Internet and printed reports*	*2011*	*1*	*http://www.ise.fraunhofer.de/de/presse-und-medien/jahresberichte*	*yes*
27	*SLURRYBASIERTE DRAHTSÄGE¬PROZESS-ENTWICKLUNG FÜR DÜNNE WAFER*	*B. Weber*	*Annual Report*	*2012*	*Fraunhofer ISE*	*Internet and printed reports*	*2012*	*1*	*http://www.ise.fraunhofer.de/de/presse-und-medien/jahresberichte*	*yes*
28	*SLURRY BASIERTER DRAHTSÄGEPROZESS MIT*	*B. Weber*	*Annual Report*	*2013*	*Fraunhofer ISE*	*Internet and printed*	*2013*	*1*	*http://www.ise.fraunhofer.de/de/presse-und-*	*yes*

	STRUKTURIERTEN DRÄHTEN					*reports*			*medien/jahresberichte*	
29	*Surface Passivation of highly and lowly doped P-Type Silicon surfaces with PECVD Al2O3 for industrially applicable solar cell concepts*	*P. Saint-Cast*	*Proceedings of the 26th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC) in Hamburg (2011)*				*2011*			*no*
30	*21% Efficiency Silicon Heterojunvction Solar Cells produced with very high Frequency PECVD*	*A. Descoeudres*	*Proceedings of the 21st International Photovoltaic Science and Engineering Conference November 28th - December 2nd, 2011, Fukuoka, Japan*				*2011*	*426*		*no*
31	*The European Project 20plµs: 20 Percent Efficiency on Less Than 100 µm Thick Industrially Feasible Crystalline-Si Solar Cells*	*B. Terheiden*	*Proceedings of the 27th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC) in Frankfurt (2012)*	*2012*			*2012*	*1586 - 1590*	*Doi: 10.4229/27thEUPVSEC 2012-2BV.6.36*	*no*
32	*Nickel Plating on p+ Silicon - A Characterization of Contact Resistivity and Line Resistance*	*S. Seren*	*Proceedings of the 27th European Photovoltaic*	*1012*			*2012*	*1777 - 1780*	*Doi: 10.4229/27thEUPVSEC 2012-2CV.5.52*	*no*

			Solar Energy Conference and Exhibition (EU PVSEC) in Frankfurt (2012)							
33	*Study on Boron Emitter Formation by BBr3 Diffusion for n-Type Si Solar Cell Applications*	*Y. Schiele*	*Proceedings of the 28th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC) in Paris (2013)*	*2013*			*2013*	*1242 - 1247*	*Doi: 10.4229/ 28thEUPVSEC2013-2BV.2.9*	*no*
34	*Electrical and Optical Analysis of Dielectric Layers for the Advanced Passivation of BBr Diffused p^+ Emitters in n-Type c-Si Solar Cells*	*J. H. Ranzmeyer*	*Proceedings of the 28th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC) in Paris (2013)*	*2013*			*2013*	*1367 - 1370*	*10.4229/28thEUPVSEC2013-2BV.2.50*	*no*
35	*Moving beyond high open-circuit voltages in silicon heterojunction solar cells: Steps to short-circuit current densities above 39 mA/cm^2*	*Z.C. Holman*	*Proc. 39th IEEE PVSC, Tampa, Florida*	*2013*			*2013*			*no*
36	*a-Si:H/c-Si Heterojunctions: A Future Mainstream Technology for High-Efficiency Crystalline Silicon Solar Cells?,*	*C. Ballif*	*Proc. 38th IEEE PVSC, Austin, Texas,*	*2012*			*2012*			*no*
37	*Accurate Modeling of*	*M. Rüdiger*	*Energy*	*8 (2011)*	*Elsevier*		*2011*	*527*		

	Aluminum-doped Silicon		*Procedia*							
38	*Effect of Incomplete Ionization for the Description of Highly Aluminum-doped Silicon*	*M. Rüdiger*	*Journal of Applied Physics*	*110 (2011)*	*American Institute of Physics*		*2011*	*024508*		
39	*Efficiency Potential of n-type Silicon Solar Cells with Aluminum-Doped Rear p+ Emitter*	*M. Rüdiger*	*Transactions on Electron Devices*	*Vol. 59, No. 5*	*IEEE*		*2012*	*1295*		
40	*Microstructural and Electrical Properties of Different-sized Aluminum-alloyed Contacts and Their Layer System on Silicon Surfaces*	*J. Krause*	*Solar Energy Materials & Solar Cells*	*95*	*Elsevier*		*2011*	*2151*		
41	*Investigation of aluminum-alloyed local contacts for rear surface-passivated silicon solar cells*	*M. Rauer*	*Journal of Photovoltaics*	*Vol. 1, No. 1*	*IEEE*		*2011*	*22-28*		*no*
42	*Aluminum alloying in local contact areas on dielectrically passivated rear surfaces of silicon solar cells*	*M. Rauer*	*Electron Device Letters*	*Vol. 32, No. 7*	*IEEE*		*2011*	*916-918*		*no*
43	*Alloying from screen-printed aluminum pastes containing boron additives*	*M. Rauer*	*Journal of Photovoltaics*	*Vol. 3, No. 1*	*IEEE*		*2013*	*206-211*		*no*
44	*Nickel-plated front contacts for front and rear emitter silicon solar cells*	*M. Rauer*	*Energy Procedia*	*38*	*Elsevier*		*2013*	*449-458*		*no*
45	*Investigation of Aluminum-boron Doping Profiles Formed by Coalloying from Screen-printed Pastes*	*M. Rauer*	*Energy Procedia*	*43*	*Elsevier*		*2013*	*93-99*		*no*
46	*Further analysis of aluminum alloying for the formation of p+ regions in silicon solar cells*	*M. Rauer*	*Energy Procedia*	*8*	*Elsevier*		*2011*	*200-206*		*no*
47	*Incomplete ionization of aluminum in silicon and its*	*M. Rauer*	*Journal of Applied Physics*	*Vol. 114*	*AIP*		*2013*	*203702*		*no*

	effect on accurate determination of doping profiles									
48	*Status and Perspectives of n-type Silicon Solar Cells with Aluminium-alloyed Rear Emitter*	*C. Schmiga*	*Proc. 27th EUPVSEC*		*WIP-Renewable Energies*		*2012*	*915*		

Table A2: List of all dissemination activities (publications, conferences, workshops, web sites/applications, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters).

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES

NO.	Type of activities[3]	Main leader	Title	Date/Period	Place	Type of audience[4]	Size of audience	Countries addressed
1	20plus Dissemination Workshop (after nPV Workshop; for details see MS38)	ENI	Industrially feasible processes for the next generation of high efficiency and thin crystalline silicon solar cells	24th April 2013	Chambery (France)	Scientific Community, Industry	49	European level
2	28th EUPVSEC, Paris, France - oral presentation	EPFL	C. Ballif: High-Efficiency Crystalline Silicon Cells Based on Heterojunction Contacts: Improving Optical Performances and Lowering Metallisation Costs	*2013*	Paris			
3	28th EUPVSEC, Paris, France - oral presentation	EPFL	M. Filipič: Contribution of inversion layer to lateral transport in amorphous silicon / crystalline silicon heterojunction solar cells	*2013*	Paris			
4	28th EUPVSEC, Paris, France - oral presentation	EPFL	J. Geissbuehler: High-efficiency silicon heterojunction solar cells with electrodeposited copper metallization	*2013*	Paris			
5	Silicon PV, Hameln, Germany - oral presentation	EPFL	E.M. El Mamhdi: Mestability versus irreversibility in a-Si:H degradation – Understanding passivation in high-efficiency silicon heterojunction solar cells	*2013*	Hameln			

7[3] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media b8riefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[4] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias, Other ('multiple choices' is possible).

6	Silicon PV, Hameln - oral presentation	EPFL	B. Demaurex: Metastability of the a-Si :H/c-Si interface during silicon heterojunction solar cell fabrication	*2013*	Hameln			
7	Silicon PV, Hameln - oral presentation	EPFL	Z.C. Holman: Understanding and optimizing the rear internal reflectance of silicon solar cells	*2013*	Hameln			
8	27th EUPVSEC, Frankfurt, Germany - oral presentation	EPFL	J.P. Seif: Silicon Oxide Layers for High Efficiency Silicon Heterojunction Solar Cells	*2012*	Frankfurt			
9	2nd Silicon PV, Leuven. Belgium - oral presentation	EPFL	S. De Wolf: Light-induced degradation of a-Si:H studied by a-Si:H/c-Si Probes	*2012*	Leuven			
10	26th EUPVSEC, Hamburg, Germany - oral presentation	EPFL	C. Ballif: High-efficiency silicon heterojunction solar-cells: From basics to pilot lines	*2011*	Hamburg			
12	26th EUPVSEC, Hamburg, Germany - oral presentation	EPFL	S. De Wolf: Very-high open-circuit voltages in silicon heterojunction solar cells: role of a-Si:H/c-Si interface passivations	*2011*	Hamburg			
13	1st Silicon PV conference, Freiburg, Germany - oral presentation	EPFL	C. Ballif: High-efficiency silicon heterojunction solar-cells: From physics to production lines	*2011*	Freiburg			
14	1st Silicon PV conference, Freiburg, Germany - oral presentation	EPFL	A. Descoeudres: Silane plasma diagnostics for high-efficiency silicon heterojunction solar	*2011*	Freiburg			
15	Presentation at the SiliconFOREST, Falkau, Germany, March 06, 2012 - oral presentation	UKON	Y. Schiele: Screen-Printed “PhosTop” Solar Cells from < 100 µm Thick n-Type Si Wafers	*2012*	Falkau			
16	Presentation at the nPV Workshop, Amsterdam, the Netherlands, May 15, 2012 -	UKON	Y. Schiele: 19% Efficient Screen-Printed PhosTop Solar Cells from 100 µm Thin n-Type Si Wafers	*2012*	Amsterdam			

	oral presentation							
17	20plµs Workshop, Chambéry, France, April 24, 2013 - oral presentation	UKON	Y. Schiele: 100 µm Thin All Screen Printed n-Type Solar Cells with Al Alloyed Rear Emitter	*2013*	Chambéry			
18	Tech. Digest 23rd PVSEC, Taipei, Taiwan - oral presentation	EPFL	A. Descoeudres: Recent progress in high-efficiency silicon heterojunction solar cells at EPFL	*2013*	Taipei			
19	48th MIDEM, Otočec, Slovenia - oral presentation	EPFL	M. Filipič: Analysis of parasitic light absorption losses in ITO layers at the back of Si heterojunction solar cell	*2012*	Otočec			
20	Tech. Digest 21st PVSEC, Fukuoka, Japan - oral presentation	EPFL	S. De Wolf: Light-induced degradation of a-Si:H studied with a-Si:H/c-Si probes	*2011*	Fukuoka			
21	ICANS, Toronto, Canada - oral presentation	EPFL	J. Holovský: Amorphous/Crystalline Silicon Interfaces: Correlation between Infrared Spectroscopy and Electronic Passivation Properties	*2013*	Toronto			
22	ICANS, Toronto, Canada - oral presentation	EPFL	S. De Wolf: High-efficiency Silicon heterojunction solar cells	*2013*	Toronto			
23	ICANS, Toronto, Canada - oral presentation	EPFL	J.P. Seif: Thin microcrystalline layers for application in silicon heterojunction solar cells	*2013*	Toronto			
24	2nd Annual Plenary FLASH meeting, Eindhoven, the Netherlands - oral presentation	EPFL	S. De Wolf: Advances in silicon heterojunction solar cells at EPFL		Eindhoven			
25	4th Workshop on Contacting Silicon Solar Cells, Konstanz,	EPFL	J. Geissbühler: Electrodeposited copper front metallization for High-efficiency silicon heterojunction	*2013*	Konstanz			

	Germany - oral presentation		solar cells						
26	European Commission 20Plus Project Workshop, Chambery, France - oral presentation	EPFL	S. De Wolf: Key steps to achieving high-efficiency Silicon heterojunction solar cells on 100 µm wafers	*2013*	Chambéry				
27	n-PV workshop, Chambery, France - oral presentation	EPFL	Z.C. Holman: Long wavelength light management in high-efficiency silicon heterojunction solar cells	*2013*	Chambéry				
28	MRS 2013 Spring Meeting, San Francisco, California - oral presentation	EPFL	Z.C. Holman: Silicon nanocrystals as downshifters and microcrystalline growth templates in silicon solar cells	*2013*	San Francisco				
29	MRS 2013 Spring Meeting, San Francisco, California - oral presentation	EPFL	M.G. Deceglie: Lateral carrier flow near the heterointerface in amorphous/crystalline Silicon Heterojunction Solar Cells	*2013*	San Francisco				
30	MRS 2013 Spring Meeting, San Francisco, California, 2013 - oral presentation	EPFL	S. De Wolf: High-efficiency p- and n-type silicon heterojunction solar cells	*2013*	San Francisco				
31	5th International Workshop on Innovative Solar Cells, Tsukuba, Japan - oral presentation	EPFL	S. De Wolf: , Silicon photovoltaics bases on thin-film and heterojunction technology: Current status and future developments	*2013*	Tsukuba				
32	Korea-EU International Symposium on PV, Busan, Korea - oral presentation	EPFL	A. Descoeudres: High-efficiency silicon heterojunction solar cells and n- and p-type wafer	*2012*	Busan				
33	Tech. Digest 22nd PVSEC, Hangzhou, China - oral presentation	EPFL	S. De Wolf: High-efficiency p- and n-type silicon heterojunction solar cells	*2012*	Hangzhou				

34	TCM 2012, Crete, Greece - oral presentation	EPFL	L. Barraud: Hydrogen-doped indium oxide/indium tin oxide bilayers for high-efficiency silicon heterojunction solar cells	*2012*	Crete			
35	MRS 2012 Spring Meeting, San Francisco, California - oral presentation	EPFL	A. Descoeudres: Improved Amorphous/Crystalline Silicon Interface Passivation for High-efficiency Heterojunction Solar Cells	*2012*	San Francisco			
36	MRS 2012 Spring Meeting, San Francisco, California - oral presentation	EPFL	Z.C. Holman: Key steps to achieving high-efficiency Silicon heterojunction solar cells on 100 µm wafers	*2012*	San Francisco			
37	MRS 2012 Spring Meeting, San Francisco, California - oral presentation	EPFL	Z.C. Holman: Light management in silicon heterojunction solar cells	*2012*	San Francisco			
38	MRS 2012 Spring Meeting, San Francisco, California - oral presentation	EPFL	S. De Wolf: Staebler-Wronski Effect studied by a-Si:H/c-Si Probes	*2012*	San Francisco			
39	4th International Workshop on Thin-Film Silicon Solar Cells, Neuchâtel, Switzerland - oral presentation	EPFL	S. De Wolf: Properties of a-Si:H layers for silicon heterojunction solar cells	*2012*	Neuchâtel			
40	Plasma 2011, Kanazawa, Japan - oral presentation	EPFL	S. De Wolf: Plasma diagnostics for high-efficiency silicon heterojunction solar cells	*2011*	Kanazawa			
41	Plasma 2011, Kanazawa, Japan - oral presentation	EPFL	S. De Wolf: Plasma diagnostics for high-efficiency silicon heterojunction solar cells	*2011*	Kanazawa			
42	SUNday 2011, Utrecht, the Netherlands - oral presentation	EPFL	S. De Wolf: Amorphous / crystalline silicon heterojunction solar-cells	*2011*	Utrecht			

43	MRS 2011 Spring Meeting, San Francisco, California - oral presentation	EPFL	B. Demaurex: Sputtering-induced defects at a-Si:H/c-Si interfaces	*2011*	San Francisco			
44	MRS 2011 Spring Meeting, San Francisco, California - oral presentation	EPFL	S. De Wolf: Nature of intrinsic a-Si:H/c-Si interface passivation	*2011*	San Francisco			
45	7th Workshop on the Future Direction of Photovoltaics, Tokyo, Japan - oral presentation	EPFL	S. De Wolf: High-efficiency silicon heterojunction solar-cells: From physics to production lines	*2011*	Tokyo			
46	20plμs Workshop, Chambéry, France, April 24, 2013 - oral presentation	ENI	F. Sebastiano Grasso: Environmental sustainability of high industrially feasible c-Si solar cells	*2013*	Chambéry			
47	20plμs Workshop, Chambéry, France, April 24, 2013 - oral presentation	HQC	T. Ballmann: Transfer of the 20plus high efficiency cell structure into pilot line production	*2013*	Chambéry			
48	20plμs Workshop, Chambéry, France, April 24, 2013 - oral presentation	ISE	C. Schmiga: n-type Silicon Solar Cells with Local Aluminium-alloyed Emitters by Applying the p-type PERC Fabrication Process	2013	Chambéry			
49	20plμs Workshop, Chambéry, France, April 24, 2013 - oral presentation	SCT	D. J. Morrison: Fabrication of Laser Grooved Buried Contact Silicon Solar Cells	2013	Chambéry			
50	20plμs Workshop, Chambéry, France, April 24, 2013 - oral presentation	EPFL	S. De Wolf: Key steps to achieving high-efficiency Silicon heterojunction solar cells on 100 μm wafers	2013	Chambéry			
51	20plμs Workshop, Chambéry,	EPFL	B. Michl: Efficiency Limiting Bulk Recombination	2013	Chambéry			

	France, April 24, 2013 - oral presentation		Analysis ELBA Applied to Thin Solar Cells					
52	20plµs Workshop, Chambéry, France, April 24, 2013 - oral presentation	ISE	B. Weber: Challenges in Wafering of Thin Silicon Wafers ≤120 µm	2013	Chambéry			
53	27th EUPVSEC, Frankfurt, Germany - oral presentation	ISE	C. Schmiga: Status and Perspectives of n-type Silicon Solar Cells with Aluminium-alloyed Rear Emitter	2012	Frankfurt			
54	1st nPV Workshop, Konstanz, Germany – oral presentation	ISE	C. Schmiga: Aluminium-alloyed Emitters for n-type Silicon Solar Cells	2011	Konstanz			
55	37th IEEE PVSC, Seattle, USA, June 2011 – oral presentation	ISE	M. Rauer: Investigation of Aluminum-alloyed Local Contacts for Rear Surface-passivated Silicon Solar Cells	2011	Seattle			
56	2nd nPV Workshop, Amsterdam, The Netherlands - oral presentation	ISE	M. Rauer: Alloying of Screen-printed Aluminum Pastes Containing Boron Additives	2012	Amsterdam			
57	4th Metallization Workshop, Konstanz, Germany - oral presentation	ISE	M. Rauer: Investigation of Aluminum-boron Doping Profiles Formed by Coalloying of Screen-printed Pastes	2013	Konstanz			

Section B (Confidential[5] or public: confidential information to be marked clearly)
Part B1

There were no applications for patents, trademarks, registered designs.

Part B2

The following Table B2 specify the exploitable foreground.

Table B2: Exploitable Foreground. If the 3rd column is marked with "Yes", the content is confidential and may NOT be made public).

Type of Exploitable Foreground[6]	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[7]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	Properties of boron etch back emitter	Yes		Knowledge	Silicon solar cell processing			UKON
General advancement of knowledge	Ni plating on p+-doped Si layers	Yes		Knowledge	Silicon solar cell processing			UKON
General advancement of knowledge	Handling of thin large area mono- and multicrystalline Si wafers.	Yes		Knowledge	Silicon solar cell processing			UKON
GENERAL ADVANCEMENT OF	Development for ultra-high Voc cells, with	Yes		Increased know-how	Silicon solar cell processing;			EPFL

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[5] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[7] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[6]	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[7]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
KNOWLEGDE	processes allowing close to 750 mV				PV industry			
GENERAL ADVANCEMENT OF KNOWLEGDE	Handling of thin wafers, and control of parasitic absorption	Yes		Increased knowledge	Silicon solar cell processing; possibly semiconductor industry			EPFL
GENERAL ADVANCEMENT OF KNOWLEGDE	Cells with controllolabe T coefficient	Yes		Process know-how	Silicon solar cell processing; PV industry			EPFL
GENERAL ADVANCEMENT OF KNOWLEGDE	With the help of the 20plus project there is also currently strong general industrial interest for such n-type technology in Europe	Yes		Better link between Research Institute and Industry	PV industry			EPFL
General advancement of knowledge	Advanced sawing process development using structured wires	No		Knowledge	Silicon solar cell processing; possibly semiconductor industry			Fraunhofer ISE
General advancement of knowledge	Efiiciency Limiting Bulk Recombination Analysis (ELBA) Tool	No		Knowledge; Service measurements at ISE	Sliicon Material Characterisation	As of now		Fraunhofer ISE
General advancement of knowledge	Advanced layers for passivation of silicon surfaces	No		Knowledge	Silicon solar cell processing			Fraunhofer ISE
General advancement of knowledge	Advanced metallisation pastes for Al-alloyed contacts	No		Knowledge	Silicon solar cell processing			Fraunhofer ISE
Exploitation of	Handling prototype for	Yes		Technology can	Silicon solar cell			MST

Type of Exploitable Foreground[6]	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[7]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
results through innovation	one side contactless wafer handling of min. 100µm thin wafer with high yield successfully demonstrated			be adapted in different handling stations, where problems with current technologies occurs	processing; possibly semiconductor industry			

Partners Hanwha Q Cells and ENI provided additional explanations about the exploitable foreground (CONFIDENTIAL):

HQC (confidential)

- **Exploitation of results**

At the German site, Hanwha Q CELLS operates the Reiner-Lemoine Research Centre, including a pilot line for cell processing and a sophisticated characterization laboratory. In the R&D centre all production relevant equipment is available for all kind of cell c-Si processing. Located next to it HQC operates a production line with a cell capacity of 200 MWp. Developed new solar cell concepts and technologies can be scaled-up fast from research level to mass- production.

With this setup HQC was eligible to participate in the project as industrial partner and care for the exploitation of the project outcomes.

The demonstration of pilot-production of new cell concepts within the Research Line has the following goals:
- qualification
- proof of manufacturing capability
- Optimization of cell concepts and corresponding production processes

The priorities of pilot line operation are:
- Fast transfer and realization of innovations
- Base-line production of innovations for yield and process learning

In the 20plμs project, 20% efficiency was achieved in the pilot line on 100 µm thick industrially feasible c-Si solar cells. The influence of wafer thickness on the cell performance was simulated. It showed that the 20plμs pilot line cell concept is suitable for 100 to 200 µm thick wafers.

These valuable results are industrially feasible and stabilize and establish technological leadership of HQC and thus sustain the company site with 750 employees in Germany in the long term.

At the current market situation, thin wafers are not demanded because of the strong decrease of Si-material costs within the last years. Hence thin wafers will not be implemented at the moment to the production of Hanwha Q CELLS. However, HQC is able to respond quickly to changes in wafer supply or market situation, based on the good results of the 20plμs project.

ENI (confidential)

Within the 20plus project significant attention was paid to socio-environmental-economic aspects.

First of all the 20plus technology was analyzed from the technological point of view and the scalability to pilot line production was assessed. Within the investigated technologies, the PHT process turned out to be the readiest for a possible inline implementation, due to process high compatibility with module integration. Within the project, it was shown that it is possible to manufacture high efficient solar cells out of silicon wafers with 120um starting thickness. In terms of costs, it was found that processing cells with reduced thickness and enhanced performances can potentially bring about a lowering of the manufacturing costs (€/Wp). The adoption of thinner wafers turned out to play a relevant role. In fact, a lower use of silicon per wafer can lead to a higher exploitation of ingots.

If further technological enhancements can be achieved and the manufacturing process can be targeted to mass production volumes, 20plus devices can be proposed as potential breakthrough technologies, capable of lowering down the production costs. Further beneficial effects on costs are expected with the adoption of an integrated fab (silicon manufacturing, wafering, cells processing and module assembling) integrating the recycling of by-products and wastes.

Then, all the aspects above can act as driving force in the lowering of the PV-generated kWh cost and ultimately target the spread out of PV-systems to reach a broader distributed electricity generation scenario in the EU.

On the environmental side, a life cycle analysis was performed to assess the sustainability of the 20plus technology. For PV-devices/systems, typically life cycle analyses are focused on the calculation of GWP impacts and EPBT. Instead, within the 20plus project, we tried to depict a wider and detailed picture of the impacts. According to the EDIP methodology, in total ten different impact categories were investigated for each single manufacturing step of the 20plus process flows. Such extended assessment led to the identification of the impacts on water, air and soil. Besides, such approach allowed us to identify the critical steps and suggest on what steps to pay attention, should it be developed a more environmentally friendly process.

From the environmental point of view, it was found that lower impacts, lower values of embodied energy and shorter energy payback times can be achieved if 20plus technology-based PV-systems are installed.

Therefore, PV-systems applying the 20plus technology are more environmentally sustainable than the ones applying the present industrial reference technology.

The observed beneficial effects on costs and environmental performances are only possible with a combination of cells with high efficiency and wafers with reduced thickness. Therefore, the development of industrial tools able to manufacture efficiently large volumes of 120um thick wafers plays a key role on the market entry and success of 20plus cells.

All the major results and the considerations discussed herein were disseminated to PV-professionals and PV-industries during the 20plµs Workshop held on 24th of April 2013 in Chambéry (France) with the title "Industrially feasible processes for the next generation of high efficiency and thin crystalline silicon solar cells".

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: 256695

Title of Project: 20plμs

Name and Title of Coordinator: Dr. Barbara Terheiden

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'*	***0Yes XNo***
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	
• Did the project involve patients?	
• Did the project involve persons not able to give consent?	
• Did the project involve adult healthy volunteers?	
• Did the project involve Human genetic material?	
• Did the project involve Human biological samples?	
• Did the project involve Human data collection?	
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	
• Did the project involve Human Foetal Tissue / Cells?	
• Did the project involve Human Embryonic Stem Cells (hESCs)?	
• Did the project on human Embryonic Stem Cells involve cells in culture?	
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	
• Did the project involve tracking the location or observation of people?	
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	

• Were those animals transgenic small laboratory animals?	
• Were those animals transgenic farm animals?	
• Were those animals cloned farm animals?	
• Were those animals non-human primates?	
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	
DUAL USE	
• Research having direct military use	0 Yes 0 No
• Research having the potential for terrorist abuse	

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	1	
Work package leaders	3	4
Experienced researchers (i.e. PhD holders)	8	14
PhD Students	3	4
Other	8	22

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**5**
Of which, indicate the number of men:	1

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?
○ Yes
○ 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	○	○	○	○	○

X Other: On the project website we provided a link to the European Platform of Women Scientists

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 :
UKON: 2 Pupils joined for a day, 1 Bachelor and 1 Master thesis were conducted, about 5 students joined to learn scientific working, BoGy (practical training for about 3 pupils to get first job orientation)
ISE: girls science day; BoGY Praktika (practical training for about 36 pupils to get first job orientation)
○ 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[8]: 2.3
○ Associated discipline[8]:1.2, 2.2
○ Associated discipline[8]:

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

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[8] Insert number from list below (Frascati Manual).

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		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
Education, Training, Youth		Foreign and Security Policy		Space	
Employment and Social Affairs		Fraud		Taxation	
		Humanitarian aid		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?	**48**
To how many of these is open access[9] provided?	**currently under process**
How many of these are published in open access journals?	
How many of these are published in open repositories?	
To how many of these is open access not provided?	
Please check all applicable reasons for not providing open access:	
X 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[10]: ……………	

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).*		**None**
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?		**None**
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,	X	None of the above / not relevant to the project
X	Difficult to estimate / not possible to quantify		

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[9] Open Access is defined as free of charge access for anyone via Internet.
[10] For instance: classification for security project.

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?

X Yes (Werner Warmuth, PSE) ○ 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?

☐ Press Release
☐ Media briefing
☐ TV coverage / report
☐ Radio coverage / report
X Brochures /**posters** / flyers
☐ DVD /Film /Multimedia

☐ Coverage in specialist press
☐ Coverage in general (non-specialist) press
☐ Coverage in national press
☐ Coverage in international press
☐ Website for the general public / internet
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
☐ Other language(s)

X English

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]