

METHODS AND APPARATUS FOR REGENERATION OF DEGRADED PHOTOVOLTAIC SOLAR CELLS

TECHNICAL FIELD

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The present disclosure relates to regeneration of degraded photovoltaic solar cells.

BACKGROUND

10 Silicon material based photovoltaic (PV) technologies constitute over 90% of globally installed photovoltaic. According to the International Technology Roadmap of Photovoltaics (ITRPV, 2021) silicon based PV technology accounted for 93% of total solar cell production in 2020. Silicon materials are further differentiated into p-type or n-type silicon materials, due to different growth processes. Currently, the PV industry
15 is dominated by p-type silicon materials, partly due to the maturity of the passivated emitter and rear contact (PERC) technology as well as the competitive pricing of p-type silicon materials as compared to the n-type counterparts. In particular, p-type multi-crystalline silicon solar cell technology benefits from the lowest manufacturing costs as compared to mono-crystalline silicon solar cell technologies. Despite the
20 continuous advancement in solar cell technologies, it has been found that silicon-based PV technology are susceptible to outdoor performance degradation, namely light-induced degradation (LID) and light-and-elevated temperature induced degradation (LeTID) for both p-type and n-type silicon materials, especially on lower quality silicon materials. This degradation is more pronounced for multi-crystalline
25 silicon solar cells due to the high density of grain boundaries within the multi-crystalline silicon wafer bulk which can act as active recombination sites for the photogenerated charge carriers. Although this degradation can be recovered naturally over time, the process varies greatly in time frame, causing an undesirable fluctuation in performance. This could cause cell manufacturers \$390m based on an estimation
30 made in 2017. Various studies were conducted for the p-type silicon materials, and experimental results suggest that the formation of boron-oxygen (B-O) defects within such materials were responsible for the performance degradation. It was subsequently observed that the presence of hydrogen and the manipulation of its charged state plays a crucial factor in the mitigation of the performance degradation. The hydrogen

sources could come from the deposited dielectric layers or from external inputs. The hydrogen atoms in the desired charge state within the silicon wafer bulk will be more effective towards passivating recombination sites within the device, which improves the overall solar cell performance.

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The practical and financial limitations caused by LID / LeTID in silicon solar cells have driven much research into various methods and parameters for regenerating B-O defects, thus recovering the solar cells' performance. Two major solar cell level approaches to regeneration are illumination-based regeneration and current injection-based regeneration. While researchers will agree on the usage of hydrogen to passivate the defects within both types of silicon solar cell, there is yet to be an aligned agreement on the optimal conditions to adopt for the regeneration process. The regeneration process has to be cost effective, efficient, and have high throughput to be able to integrate into the solar cell manufacturing line.

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SUMMARY

According to a first aspect of the present disclosure, a method of regenerating a degraded solar cell is provided. The method comprises: illuminating the degraded solar cell with light having a wavelength of less than 1050nm and an intensity of at least 3 suns.

Methods of the present disclosure provide the ability to deliver a rapid illumination-based regeneration process in a matter of seconds or minutes, in line with industrial throughput requirements. The methods provide an illumination-based advanced regeneration process for p-type multi-crystalline silicon solar cells, to maximize its performance while striving towards LID- / LeTID-free solar systems. The methods provide scalability and adaptability to different solar cells designs and structures (p-type and/or n-type) and dimensions. Further, light-induced degradation prevention may be provided for new solar cells, thus prolonging the solar modules' usability lifespan and reducing the cost of ownership (lower levelized cost of energy, LCOE).

In an embodiment, the method comprises heating the degraded solar cell before illuminating the degraded solar cell.

In an embodiment, the method comprises cooling the degraded solar cell after illuminating the degraded solar cell.

- 5 In an embodiment, the degraded solar cell is heated to a temperature of at least 50°C, and preferably at least 70°C.

In an embodiment, the degraded solar cell is heated to a temperature of less than 350°C.

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In an embodiment, the degraded solar cell is illuminated for a period of at least 5 seconds.

In an embodiment, the degraded solar cell is illuminated for a period of less than 60 seconds.

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In an embodiment, the intensity of the illumination is at least 5 suns, preferably at least 10 suns and more preferably at least 20 suns.

- 20 In an embodiment, heating the degraded solar cell comprises contact heating the degraded solar cell.

In an embodiment, cooling the degraded solar cell comprises contact cooling the degraded solar cell.

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Contact heating and / or contact cooling allows precise control over the heating / cooling processes.

- 30 According to a second aspect of the present disclosure an apparatus for regenerating a degraded solar cell is provided. The apparatus comprises a light source configured to illuminate the degraded solar cell with light having a wavelength of less than 1050nm and an intensity of at least 3 suns.

In an embodiment, the light source is a laser.

In an embodiment, a heating unit configured to heat the degraded solar cell before the degraded solar cell is illuminated by the light source.

- 5 In an embodiment, the heating unit is configured to heat the degraded solar cell to a temperature of at least 50°C, and preferably at least 70°C.

In an embodiment, the heating unit is configured to heat the degraded solar cell to a temperature of less than 350°C.

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In an embodiment, the apparatus further comprises a cooling unit configured to cool the degraded solar cell after the degraded solar cell is illuminated by the light source.

- 15 In an embodiment, the apparatus further comprises a transportation belt configured to move the degraded solar cell from position under the heating unit to a position under light source.

In an embodiment, the heating unit is configured to contact heat the degraded solar cell.

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In an embodiment, the cooling unit is configured to contact cool the degraded solar cell.

- 25 In an embodiment, the apparatus is configured such that the degraded solar cell is illuminated for a period in the range of 5 to 60 seconds.

BRIEF DESCRIPTION OF THE DRAWINGS

- 30 In the following, embodiments of the present invention will be described as non-limiting examples with reference to the accompanying drawings in which:

FIG.1 shows an apparatus for regeneration of degraded photovoltaic solar cells according to an embodiment of the present invention;

FIG.2 is a flowchart showing a method for regeneration of degraded photovoltaic solar cells according to an embodiment of the present invention;

FIG.3 shows photoluminescence images of multi-crystalline silicon solar cells subjected to a light soaking process typical of outdoor usage and followed by different regeneration design of experiment (DOE) splits with increasing process temperatures; and

FIG.4(a) to FIG.4(d) show a graphical summary of results of an extended DOE study to determine an optimal process temperature.

DETAILED DESCRIPTION

FIG.1 shows an apparatus for regeneration of degraded photovoltaic solar cells according to an embodiment of the present invention. The apparatus 100 comprises a transportation belt 110 which moves over a processing stage 120. A heating unit 130 comprising heating elements 135 is provided above the transportation belt 110. A light source 140 which provides illumination 150 is provided above the transportation belt 110 adjacent to the heating unit 130. A cooling unit 160 comprising cooling elements 165 is provided above the transportation belt 110 adjacent to the light source 150. A cooling robot arm 170 extends from the cooling elements 165.

As shown in FIG.1, in use, degraded solar cells 180 are placed on the transportation belt 110. The degraded solar cells 180 are moved by the transportation belt 110 in a transport direction 190 which moves the degraded solar cells 180 across the processing stage 120. Initially, the degraded solar cells 180 are heated by the heating elements 135, then the degraded solar cells 180 move under the light source 140. While the degraded solar cells 180 are under the light source 140, the illumination 150 is incident on the degraded solar cells 180. As is described in more detail below, the illumination 150 regenerates the degraded solar cells 180. Following the illumination of the degraded solar cells 180, the regenerated degraded solar cells 180 are cooled by the cooling elements 165.

FIG.2 is a flowchart showing a method for regeneration of degraded photovoltaic solar cells according to an embodiment of the present invention. The method 200 shown in FIG.2 may be carried out by the apparatus 100 shown in FIG.1.

5 In step 210, the degraded solar cells 180 are heated by the heating elements 135. This may be achieved by the degraded solar cells 180 moving under the heating elements 135 on the transportation belt 110.

10 In step 220, the degraded solar cells 180 are illuminated by the light source 140. Again, this may be achieved by the degraded solar cells moving under the light source 140 on the transportation belt 110.

15 In step 230, the degraded solar cells 180 are cooled by the cooling elements 165. This may be achieved by the degraded solar cells moving under the cooling elements 165 on the transportation belt 110.

Transport mechanism: The solar cells to undergo regeneration will be placed on a transportation belt, which will be moving continuously in a clockwise direction. The belt speed will be adjustable, ranging from centimeters/second to meters/second, depending on the desired regeneration process time. This setup can be conveniently integrated within the existing solar cells' metallization process or constructed as a standalone, prior to the electrical measurements.

25 Illumination control: The process requires the injected photons to have sufficient energy to overcome the silicon bandgap energy (1.12eV). Thus, the targeted wavelength for regeneration should be lower than 1050 nm, with suitable illumination source wavelengths spanning from infrared to visible (i.e. 300 to 1050 nm). It is to be further noted that wavelengths with significantly lower wavelengths can lead to substantial substrate heating which will require further process optimization for the transport, heating, and cooling elements. The illumination light intensity is to be adjustable from less than one sun intensity ($<100\text{mW/cm}^2$) and up to 100 suns intensity (10W/cm^2). The illumination light sources can include but are not limited to the following: (a) laser, (b) halogen incandescent lamps, (c) fluorescent light, (d) metal halide light sources, (e) xenon strobe lamps, (f) IR lamps, (g) light and sunlight

concentrators and (h) LEDs. The placement of the illumination light source can be set up to target a single solar cell at every instance with the desired process time and surface temperature controlled by the optimized belt speed and heating/ cooling elements. Another placement approach is to adopt an illumination light source array
5 between the heating and cooling elements. For the latter approach, the footprint is expected to be larger, but a larger throughput is possible with lower regeneration process times per individual light source.

Process time control: Depending on the illumination intensity, the regeneration time
10 per solar cell can range from as fast as 5 seconds to several minutes. With increasing illumination intensity, a higher concentration of photon flux with sufficient energy is delivered, thus maximizing the regeneration effectiveness in a matter of seconds. In contrast, when a lower illumination intensity (<20 suns) is adopted, the optimal process time required is expected to be increased to achieve the same outcome.

Process temperature control: The surface and bulk temperature of the hydrogenated
15 solar cells will also contribute to the effectiveness of the regeneration process, and can range from room temperature 25°C (300K) up to 350°C (623K). This is established via the rapid heating and cooling elements in order to fix and lock in the desired
20 hydrogen charge state as fast as possible once the regeneration process is completed. This is to prevent the hydrogen from transforming back into the default state. Once regeneration is completed, the treated solar cells are to be subjected to rapid cooling to lock in the desired hydrogen charge state, which can include: (1) thermoelectric cooling (Peltier effect), (2) cold ambient air exposure via fans, (3) cold nitrogen gas
25 exposure, (4) heat sink-based heat transfer, (5) liquid-based cooling and (6) cooling water.

In the embodiment described above with reference to FIG.1 and FIG.2, the degraded
30 solar photovoltaic cells are heated prior to illumination and are cooled following the illumination. However, embodiments are envisaged which comprise just heating and illumination or illumination alone. Thus, the cooling unit and the heating unit may be omitted from the apparatus for regeneration of degraded photovoltaic solar cells.

As proof of concept, to demonstrate the effectiveness of the advanced regeneration process, p-type multi-crystalline silicon solar cells were fabricated and subjected to the advanced regeneration process optimization studies. The key highlights are listed below:

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P-type Multi-Crystalline Silicon Solar Cells

Starting with p-type multi-crystalline silicon solar cells, these solar cells were subjected to a design of experiment (DOE) regeneration study which varies the regeneration process temperature from room temperature (25°C) to 120°C in steps of 50°C, while maintaining an exposure time of 15 seconds and an illumination intensity of 20 suns using a laser operating in the wavelength range of 960 - 980nm. Prior to the regeneration studies, these solar cells were intentionally degraded via light soaking (1 sun, 70°C, 69 hours) to emulate the typical outdoor PV module operating conditions.

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An overview of the investigated design of experiments (DOE) to determine the regeneration process window for p-type multi-crystalline silicon solar cells is shown in table 1 below.

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Table 1: An overview of the investigated design of experiments (DOE)

DOE split #	Illumination intensity [suns]	Stage temperature [°C]	Time [s]
Control	N.A.	N.A.	N.A.
1	20	25	15
2	20	70	15
3	20	120	15

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The process flow begins with subjecting as received samples to a light soaking degradation step (1 sun, 70°C, 69 hours) to simulate outdoor usage, followed by the regeneration DOE studies. Solar cell characterization was performed (IV measurement, photoluminescence and electroluminescence) at different stages of the

process flow to compare and evaluate the technical feasibility for performance recovery for p-type multi-crystalline silicon solar cells.

FIG.3 shows photoluminescence images of multi-crystalline silicon solar cells subjected to a light soaking process typical of outdoor usage (1 sun, 70°C, 69 hours) and followed by different regeneration DOE splits with increasing process temperatures (25, 70, 120°C). It can be seen that a higher regeneration process temperature leads to a better recovery of the cell performance, as evident from the brighter intensity of photoluminescence images.

Table 2 below shows a comparison of the IV measurement results for p - type multi - crystalline silicon solar cells subjected to the DOE shown in Table 1.

Table 2: Comparison of the IV measurement results

Stage	Jsc (mA/cm ²)	Voc (V)	FF (%)	Eff (%)	Pmax (W)	Delta Eff (%), absolute	Delta Voc (mV), absolute
as received	39.97	0.630	78.00%	19.7	4.800	N.A.	N.A.
post light soaking	39.67	0.627	77.60%	19.3	4.718	- 0.35	- 3.08
post regen (DOE#1)	39.74	0.628	77.80%	19.4	4.744	- 0.24	- 2.09
post regen (DOE#2)	39.86	0.629	77.80%	19.5	4.765	- 0.15	- 1.64
post regen (DOE#3)	39.71	0.629	77.80%	19.4	4.746	- 0.23	- 1.68

The benefits from the advanced regeneration process were clearly evident after the regeneration process as seen in Table 2 and FIG.3. Despite a cell efficiency degradation of 0.35% absolute after the light soaking process (typical of outdoor operating conditions), the regeneration process in the planned DOE has demonstrated partial recovery of the performance degradation within a short regeneration period of 15 seconds. It can also be observed that a higher process temperature is beneficial

for the performance recovery, in which the same sample subjected to a process temperature of 70°C exhibited further performance recovery with a net degradation of 0.15% absolute, or equivalently a +0.2% absolute recovery.

5 However, with further increases in the process temperatures from 70°C (DOE#2) to 120°C (DOE#3), the performance recovery appears to saturate and even show signs of deterioration in the measured short circuit current. The photoluminescence (PL) images in FIG.3 provide a visual representation of the performance recovery process. Solar cells which experience lower levels of degradation tend to exhibit higher PL
10 intensity counts and brighter PL images. When a room temperature (25°C) regeneration is applied (DOE#1), the performance recovery from the degraded state is lower with a PL intensity count improvement of +1.1% relative. When the process temperature is further increased to 70°C (DOE#2), there is a significant increase in the measured PL intensity counts (+24.2% relative), and a much brighter PL image as
15 shown in Figure 1. However, for even higher process temperature of 120°C (DOE#3), the improvement in the PL intensity counts saturates as compared to DOE#2, which is consistently with the electrical measurement results in Table 2.

Table 3 below shows an extended design of experiments (DOE) from Table 1 to
20 determine the regeneration process window for p-type multi-crystalline silicon solar cells. The process flow begins with subjecting as-received samples to a light soaking degradation step (1 sun, 70°C, 48 hours) to simulate outdoor usage, followed by the regeneration DOE studies. Solar cell characterization was performed at different stages of the process flow to compare and evaluate the technical feasibility.

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Table 3: An extended design of experiments (DOE) from Table 1

DOE split #	Illumination intensity [suns]	Stage temperature [°C]	Time [s]
Control	N.A.	N.A.	N.A.
1	20	50	15
2	20	70	15
3	20	90	15

4	20	120	15
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With these positive initial findings and indications, an extended DOE study was conducted as per Table 3, varying the process temperature over a narrower range, i.e. 50, 70, 90, 120°C to determine the process window.

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FIG.4(a) to FIG.4(d) show a graphical summary of results of an extended DOE study to determine an optimal process temperature. FIG.4(a) shows a comparison of normalized cell efficiency (Eff) at different stages. FIG.4(b) shows a comparison of normalized open-circuit voltage (Voc) at different stages. FIG.4(c) shows a comparison of normalized short circuit current (Jsc) at different stages. FIG.4(d) shows a comparison of normalized fill factor (FF) at different stages. As the individual solar cells for each DOE do exhibit slight variations in the starting cell efficiencies, the normalized values are utilized instead for comparison purposes. Firstly, it is observed that the cell efficiency of the control sample degraded by 0.23% absolute upon a similar light degradation process (1 sun, 70°C, 48 hours) which is within expectations. Next, the regeneration process was applied and evaluated to be effective in recovering the degraded performance to various extents within a short 15 second exposure period as shown in FIG.4(a) to FIG.4(d). Comparison of the key solar cell performance parameters for p-type multi-crystalline silicon solar cells for both the control condition and the regenerated conditions. Overall, the performance recovery can be mainly attributed to the improvement in the bulk and surface passivation, evident from the recovery of the open-circuit voltage Voc. A higher regeneration temperature is also beneficial in maximizing the recovery potential as seen in the short circuit current (JSC) trend, while not affecting the fill factor (FF).

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Some key highlights are as listed below:

a) Cell efficiency: Improves across all investigated DOE temperatures (50, 70, 90, 120°C), although a higher regeneration temperature tends to lead to better performance recovery.

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b) Open circuit voltage VOC: Improves across all investigated DOE temperatures, and appears to reach saturation with a process temperature as low as 50°C.

c) Short circuit current JSC : Clear trend that higher DOE temperatures lead to better performance recovery.

- 5 d) Fill factor FF : Improves across all investigated DOE temperatures, and appears to reach saturation with a process temperature above 70°C.

To summarize, the effectiveness of the laser-based regeneration process for p-type multi-crystalline silicon solar cells has been demonstrated, and a wide temperature process window (50 – 120°C) is suitable to achieve the desired performance recovery. It is expected that if a lower regeneration temperature is utilized, a longer process time could be considered to achieve the same outcome as that of a higher regeneration temperature. These summarized optimum process conditions in Table 4 will guide the tool design for an effective regeneration process that is customized to p-type multi-crystalline silicon solar cell technology.

Table 4: Summary of the advanced regeneration process parameters for effective regeneration of p - type multi - crystalline silicon solar cells to mitigate the light induced degradation phenomenon.

Solar cell type	Illumination intensity [suns]	Stage temperature [°C]	Time [s]
P-Multi	≥20 suns	50 ~ 120	≥15

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The solar cell regeneration methods and apparatus described above have some clear distinct advantages over the conventional solar cell regeneration tools via belt furnace or laser illumination or current-induced injection. The key differences and benefits of methods and apparatus can be summarized as (1) decoupling of the illumination light sources from the heating sources, which allows for greater flexibility in the choice of the illumination intensity, from less than one sun intensity (<100mW/cm²) up to 100 suns intensity (10W/cm²), (2) regeneration process can be seamlessly integrated with the existing solar cell metallization process, which is right after the metallization step, so that metallized solar cells can immediately proceed for the optimized regeneration

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process before the final IV testing process, (3) reduced manpower requirements in factory manufacturing scenarios. Unlike the standalone laser illumination or current injection tools which will require additional manpower or loading systems to manually load and unload the finished solar cells from loaders, the embodiment in this disclosure
5 can be seamlessly integrated with previous processes, and (4) easy control of process time via belt speed control. The belt speed will also impact on the solar cell temperature prior to the start of the regeneration process. Thus, the appropriate regeneration process conditions can be delivered for different solar cell technologies.

10 To summarize, both the apparatus and methods aim to directly address the light-induced degradation phenomenon commonly experienced by p-type multi-crystalline silicon solar modules deployed in the outdoor environment, which negatively impacts on their electrical energy generation potential. By subjecting the brand new p-type multi-crystalline silicon solar cells to the advanced regeneration process in this
15 disclosure, prior to the solar module manufacturing process, the regenerated solar modules is expected to be more resilient to the future outdoor operating conditions as compared to non-regenerated solar modules. With this advantage, the solar modules' usability lifespan can be extended, followed by an increase in electricity collection output, thus directly reducing the cost of ownership (lower levelized cost of energy, LCOE), while promoting solar photovoltaic as the alternative renewable energy source,
20 and encouraging more adopters of PV systems and more sales.

Impact on performance and equipment warranty: (i) the regeneration takes place in a contactless manner, and thus will not cause physical impact on the solar cells, (ii) the
25 regeneration process can be implemented in low to moderate temperatures as shown in earlier results (Table 4), well within the typical solar cell manufacturing process, and (iii) the regeneration effectiveness has been demonstrated for p-type multi-crystalline silicon solar cell technologies in the earlier sections.

30 The apparatus may be configured to achieve high illumination intensity and uniformity: Besides the usage of laser-based systems, other alternatives such as: (a) halogen incandescent lamps, (b) fluorescent light, (c) metal halide light sources, (d) xenon strobe lamps, (e) IR lamps and (f) light and sunlight concentrators may be used. The

goal is to achieve the targeted illumination intensity and area uniformity for the regeneration process across entire devices.

Key advantages for the methods and apparatus of this disclosure are as follows:

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(I) Rapid regeneration process: The process time required is significantly lower (<30 seconds) as compared to most of the published reports for illumination-based (<100 seconds) and current injection-based (20~70 mins) regeneration process. Thus, it is suitable for integration into the solar cell manufacturing process, for example during or
10 after the metallization process.

(II) Scalability and adaptability: With various solar cell manufacturers adopting different silicon materials (p-type and n-type) and wafer dimensions, the optical component within the system can be adjusted conveniently to meet these varied requirements.

15 There is also flexibility in the choice of the light source, as there can be various light source candidates based on the designed wavelength range, the amount of required incident photon flux (intensity) and expected exposure time per solar cell.

(III) LID / LeTID prevention: The experimental results highlight the effectiveness of the
20 disclosed method and device for recovering the performance loss due to the light-induced degradation issue.

(IV) Extended usability periods: With a consistently higher performance at both the solar cell and system levels, it is expected that the useful lifespan of the installed PV
25 modules can be extended beyond their 20~25 years warranty period, thus bringing both performance and financial benefits to the end-customers. Eventually, if the PV modules need to be upgraded with higher power modules, the older modules which were previously regenerated can also be reutilized to lower power applications, thus minimizing the PV module waste. This has a direct impact on the expected LCOE,
30 bringing both technological and financial advantages to the solar asset owners adopting the advanced regeneration process in this disclosure. This will reduce the need for PV module replacement, thus saving costs. This will also reduce PV e-waste, and the need for PV recycling, or alternatively landfilling.

Whilst the foregoing description has described exemplary embodiments, it will be understood by those skilled in the art that many variations of the embodiments can be made within the scope and spirit of the present invention.

CLAIMS

1. A method of regenerating a degraded solar cell, the method comprising:
illuminating the degraded solar cell with light having a wavelength of less than 1050nm and an intensity of at least 3 suns.
2. The method according to claim 1, further comprising heating the degraded solar cell before illuminating the degraded solar cell.
3. The method according to claim 2, further comprising cooling the degraded solar cell after illuminating the degraded solar cell.
4. The method according to claim 2 or claim 3, wherein the degraded solar cell is heated to a temperature of at least 50°C, and preferably at least 70°C.
5. The method according to any one of claims 2 to 4, wherein the degraded solar cell is heated to a temperature of less than 350°C.
6. The method according to any preceding claim, wherein the degraded solar cell is illuminated for a period of at least 5 seconds.
7. The method according to any preceding claim, wherein the degraded solar cell is illuminated for a period of less than 60 seconds.
8. The method according to any preceding claim, wherein the intensity of the illumination is at least 5 suns, preferably at least 10 suns and more preferably at least 20 suns.
9. The method according to any one of claims 2 to 8, wherein heating the degraded solar cell comprises contact heating the degraded solar cell.
10. The method according to any one of claims 3 to 9, wherein cooling the degraded solar cell comprises contact cooling the degraded solar cell.

11. An apparatus for regenerating a degraded solar cell, the apparatus comprising a light source configured to illuminate the degraded solar cell with light having a wavelength of less than 1050nm and an intensity of at least 3 suns.
12. The apparatus according to claim 11, wherein the light source is a laser.
13. The apparatus according to claim 11 or 12, further comprising a heating unit configured to heat the degraded solar cell before the degraded solar cell is illuminated by the light source.
14. The apparatus according to claim 13, wherein the heating unit is configured to heat the degraded solar cell to a temperature of at least 50°C, and preferably at least 70°C.
15. The apparatus according to claim 13 or 14, wherein the heating unit is configured to heat the degraded solar cell to a temperature of less than 350°C.
16. The apparatus according to any one of claims 13 to 15, further comprising a cooling unit configured to cool the degraded solar cell after the degraded solar cell is illuminated by the light source.
17. The apparatus according to any one of claims 13 to 17, further comprising a transportation belt configured to move the degraded solar cell from position under the heating unit to a position under light source.
18. The apparatus according to any one of claims 13 to 17, wherein the heating unit is configured to contact heat the degraded solar cell.
19. The apparatus according to any one of claims 14 to 18, wherein the cooling unit is configured to contact cool the degraded solar cell.
20. The apparatus according to any one of claims 11 to 19, configured such that the degraded solar cell is illuminated for a period in the range of 5 to 60 seconds.