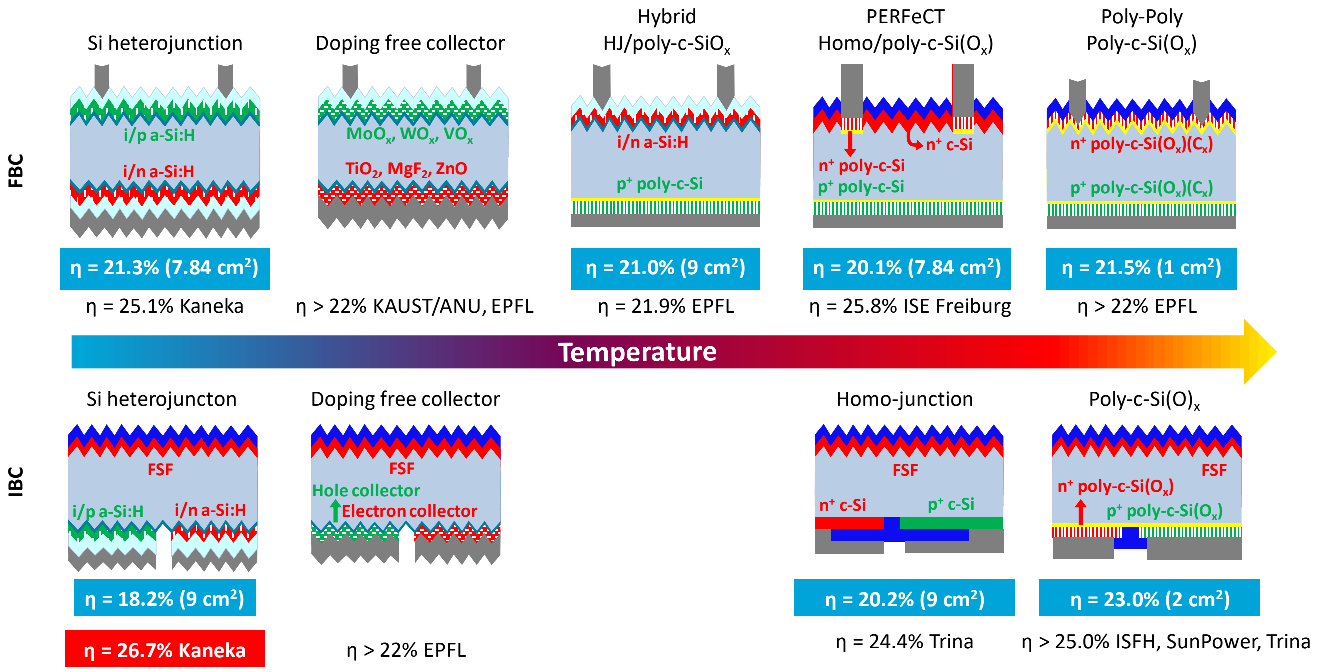
Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 2nd of April 2019

Area #1: Wafer-based c-Si solar cells at PVMD group



Title	**Toward easy industrialized, high-efficient c-Si solar cells with poly-Si passivating contacts**
Daily Supervisor(s)	Ir. Can Han (C.Han-1@tudelft.nl), Dr. Guangtao Yang (g.yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Nowadays PERx cell technologies are becoming one of the main industrialized technologies in the PV market. But there is still factors that limit the cell performances. Comparing to the Al BSF cell, the contact recombination losses in PERx cells are dramatically decreases. However, it can still be minimized by using the carrier selective passivating contact concepts: for example, the silicon hetero-junction technology, the TOPCon (poly-Si passivating contact) technology, et al. Looking at the industry PERx process technologies, *the poly-Si technology* becomes one of the most promising one that can be easily deployed into the cell process flow. Therefore, we propose this poly-Si/poly-Si FBC project to study the feasibility and potential of this technology. Within the PVMD group we have developed ***excellent*** poly-Si passivating contact layers, which have already be demonstrated to be perfect contact layers for high-efficiency solar cells. The main challenges are (1) demonstrate high FF, and (2) high Voc, or low contact losses in the solar cells. During the project, TCO layers (ITO, ZnO:Al. et al.) will be developed for contacting different polarized poly-Si materials (n-type or p-type doped), including exploration on various deposition conditions and post-treatments. Different interfacial layers (a-Si:H, SiC_x:H, et al.) between poly-Si and TCO layers will be tested to minimize the barrier at the interfaces, mainly including continuously decreasing corresponding contact resistivity values, as well as the fundamental analysis on the optimization process. Besides, optical properties of TCOs will also be considered to minimize the reflective and parasitical absorptive losses. All the materials development and solar cell fabrication will be done in the *cleanroom*.
Available from	May 2019
Type	Experimental
Internal/External	Internal

Title	**>25% IBC solar cells with ion-implanted poly-Si passivating contacts**
Daily Supervisor(s)	Dr. Guangtao Yang (g.yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	c-Si solar cells based on the poly-Si Tunnel Oxide Passivating Contact (TOPCon) is becoming one of the most promising solar cell structures that enable both high efficiency and low cost. The record efficiency for the front-rear contacted cell with TOPCon structure is 25.7%. By moving both metal contacts to the back side, the so-called interdigitated back-contact (IBC) approach, the solar cell efficiency can be improved significantly due to the absence of optical shading from the front metal-contact. The objective of this project is to improve the IBC solar cell efficiency based on the standard poly-Si IBC solar cell process flow developed at PVMD group, which was demonstrated with 23% efficiency solar cells. The main challenge is to (1) minimized the difference between the SunsVoc and Voc of the cell for improving the cell V_{oc}; (2) increase the cell FF by decreasing the series resistance of the solar cell, which can be achieved by (a) minimizing the metal resistance by Cu-plating, (b) increase the mobility of poly-Si materials by hydrogenation; (3) further improve the passivation of the front side of the cell. (4) solar cell characterization for the losses analysis. This thesis project will cover the materials study, solar cell devices fabrication and characterization. All the materials development and solar cell fabrication will be done in the *cleanroom*.
Available from	May 2019
Type	Experimental
Internal/External	Internal

Title	**High energy yield Bifacial-IBC solar cells enabled by poly-Si carrier selective passivating contacts**
Daily Supervisor(s)	Dr. Guangtao Yang (g.yang@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	By using the bifacial approach, an extra gain in the energy yield is proved comparing to the conventional FBC solar cell architecture [1]. It has been proved that the use of passivating contacts in the front-rear contacted cells and IBC cells enhances the solar cell performances by quenching the contact recombination. In this project, the passivating contacts will be used in the *bifacial IBC* solar cells. This cell architecture shows the optical gain when compared to the FBC cell, and extra energy yield enhancement when comparing to conventional FBC-bifacial and IBC solar cell architectures. From IBC to bifacial-IBC, the challenges are on (1) maintaining high FF after narrowing the metal fingers on the rear, comparting to the IBC solar cells; (2) high cell bifaciality, η_{rear}/η_{front}, which is one of the most important factors for high energy yield bifacial solar cells. Therefore, the adaption of metallization from IBC to bifacial-IBC will be the first step to tackle the FF issues. And the light in-coupling for the rear side will be applied for the later one. All the materials development and solar cell fabrication will be done in the *cleanroom*.
Available from	May 2019
Type	Experimental
Internal/External	Internal

Title	**Novel doping free carrier selective contacts on tunnelling oxides for c-Si solar cells**
Daily Supervisor(s)	Dr. Guangtao Yang (g.yang@tudelft.nl),
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Recently, the novel carrier selective contacts (CSC) based on metal oxides, for example, MoO_3, V_2O_5, TiO_2, ZnO, In_2O_3; and metal fluoride, for example, MgF_2 are used to passivating and contacting the c-Si for high efficient solar cells. The advantage of these CSCs is their absorption free properties. Such CSCs are normally structured in two ways: (1) metal-oxide/a-Si:H (passivation layer)/c-Si bulk, and (2) metal-oxide/SiO_2 (~1.5 nm, passivation layer)/c-Si bulk. For both approaches, the mechanism of carrier selectivity is the same: the work function mismatch induced high level band bending at the interfaces. With the first approach a very nice passivation can be obtained due to the a-Si:H inter layer, however, a-Si:H layer is still very absorptive, which

hinds the advantages of such CSCs. In the second approach, due to the non-absorptive SiO_2, there will be no parasitic absorption in the CSCs, which will enhance the light absorption in the bulk to the maximum point. On the other hand, this approach is much more industry friendly, as comparing to the a-Si:H layer the SiO_2 is much easier to prepare and process. However, the material optimization is much more challenging.
The preparation of such CSC layers are normally prepared via Physical Vapour Deposition (PVD), e.g. thermal/e-beam evaporation; or Atomic Layer Deposition (ALD). Both techniques will be tested in this project.
The main challenge for fabricating highly efficient solar cells with the proposed CSCs (short term focusing on V_2O_5 and TiO_2) are: (i) optimize of hole selective and electron selective materials for passivating the c-Si surface, which offer high passivation properties and carrier selectivity; (ii) the application of such CSCs in solar cells, first in front and back contacted (FBC) solar cell, and then on interdigitated back-contact (IBC) solar cells and/or bifacial solar cells (BFC).
All the materials development and solar cell fabrication will be done in the cleanroom.

Available from May 2019
Type Experimental
Internal/External Internal

Title **Copper-plated metallization on high efficiency crystalline silicon solar cells**
Daily Supervisor(s) Can Han (C.Han-1@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description The ultimate goal of solar energy is to be economically competitive with current sources of electricity. Although the price of crystalline silicon(c-Si) solar cells and the modules has dropped significantly in the last few years, the cost per Walt must go down even further. Approximately 30% of the non-base material related costs of a c-Si solar cell is contributed by the Ag in the screen printing paste. Thus, alternative metallization schemes have been developed in recent years.
The aim of this project is to study on the promising costly electro-plated Cu technology (Cu-plating) and its application in high efficiency solar cells, including: (i) exploration of seed layer before Cu-plating, since Cu has high diffusivity and solubility, which should be avoided, and on the other hand, the contact properties can be improved through such an intermediate layer. Expected seed layer is sputtered/evaporated Ti layer. (ii) utilization and optimization of Cu-plating in one of the following device configurations: silicon heterojunction (SHJ) solar cell, “poly-poly solar cell”, poly-Si-a-Si:H hybrid solar cell, interdigitated back-contact(IBC).

Available from May 2019
Type Experimental
Internal/External Internal

Title **Poly-Si(O_x) passivating contacts: from material development to high-efficient solar cells fabrication**
Daily Supervisor(s) Manvika Singh (M.Singh-1@tudelft.nl) and Dr. Guangtao Yang (g.yang@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description Poly-Si as a carrier selective contact is now a hot research topic due to the fact that this novel passivating carrier-selective contact layer showing low recombination current, which enables high-efficiency solar cells. It consists of a very thin tunnelling oxide layer on the c-Si surface and a doped poly-Si layer on top of it. However, poly-Si is quite absorptive in the form of free carrier absorption. In this project, the poly-Si material will be alloyed with oxygen to from poly-SiOx material, which is much transparent then poly-Si material, therefore a higher short circuit current is expected. Currently, research on poly-Si(O_x) passivating contacts has been limited to double side flat or single side textured wafers. The novelty of this project is that the student will be the first one to fabricate front back contacted solar cells with poly-Si(O_x) passivating contact on double side textured wafers.

The aim of this project is to: (1) optimize, in the materials level, the passivation quality of poly-Si(O_x) passivating contacts, especially the p-type doped material on textured and flat surface; (2)

To optimize the optical and passivating properties of n and p polySiOx layer on textured and flat surface with different values of RF power, pressure and gas flow ratios (3) (i) design and prepare front back contacted solar cells with poly-Si(O_x) passivating contacts on double side textured wafers, (ii) design and prepare interdigitated back contacted (IBC) solar cells with the above mentioned structure, All the materials development and solar cell fabrication will be done in the cleanroom.

Available from April 2019
Type Experimental
Internal/External Internal

Title **>24% interdigitated-back-contacted silicon heterojunction solar cell featuring novel nanocrystalline silicon oxide passivating contact stacks**
Daily Supervisor(s) Yifeng Zhao (Y.Zhao-4@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)

Short description

Currently, silicon heterojunction (SHJ) solar cell is one of the most promising photovoltaic technologies thanks to the outstanding passivation quality from the a-Si:H that enables excellent V_{OC} of the cell. Together with interdigitated-back-contacted (IBC) architecture, it enables the highest efficient, 26.7% [1], singe junction c-Si solar cell. However, the using of traditional doped a-Si as carrier-selective-contacts (CSCs) at the illumination side induce high parasitic absorption, eventually the loss of J_{SC}. In this project, the novel mixed phase material, hydrogenated nanocrystalline silicon oxide (nc-SiO_x:H), which features high transparency and high conductivity simultaneously is implemented. Due the complexity of patterning IBC cells, front-and-back-contacted (FBC) cells are manufactured and optimized as proof of concepts for IBC cells. The ongoing research till march of 2019, FBC-SHJ cell over 21.3% efficiency is demonstrated, and it keeps showing potentials for further improvements.

The main tasks of this project are: (1) passivation optimization of PECVD deposited intrinsic amorphous silicon on c-Si surfaces with different morphologies and scientific characterization of those layers by using advanced tools such as FTIR, SIMS, TEM; (2) future enhance the performance of the FBC-SHJ cells by means of engineering the opto-electrical properties and thicknesses of contact stacks and their interfaces, polishing the process flow design; (3) Eventually, implement the technologies that are developed in FBC cells to IBC-SHJ cells.

All the materials development and solar cell fabrication will be done in the cleanroom.

Available from April 2019
Type Experimental
Internal/External Internal

Title **Numerical simulation of c-Si solar cells based on TMO Carrier selective contacts**
Daily Supervisor(s) Dr. Paul Procel (p.a.procelmoya@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)

Short description

The use of carrier selective contacts (CSC) in c-Si solar cells potentially allows to overpass the limited conversion efficiency of homo-junction counterparts. The driving force of efficient CSC is the application of materials that exhibit the proper work-function to induce the proper conditions for n- or p-contact. Interestingly, due to material properties and processes, transition metal oxides (TMO) are promising candidates achieving efficiencies over 22%. However, competitive mechanisms for further improvement are still under research with the support of simulation tools. In this project, based on previously calibrated TCAD model and experimental characterization [4] we will i) validate the device modelling, ii) identify the dominant physical mechanisms, iii) propose an optimization and iv) provide guidelines for developers to achieve the most favourable parameters.

The scientific questions are:

- What are the main material parameters affecting the contact formation?
- What are the limiting physical mechanisms for n-contact and p-contact material?

- How is the recombination and transport behaviour?
- What material parameters can be controlled during the process to improve conversion efficiency?

Available from	April 2019
Type	Numerical simulations
Internal/External	Internal

Title **Development of poly-Si(C_x) passivating contacts for high-efficient c-Si based solar cells**

Daily Supervisor(s) Dr. Luana Mazzarella (l.mazzarella@tudelft.nl)

Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)

Short description

Carrier passivating contacts consists in an ultra-thin silicon oxide layer capped with doped polysilicon layers. This device concept showed very low recombination current with remarkable efficiency of 25.8%.
The aim of this project is to:

i. optimize at material level poly-Si passivating contacts alloyed with carbon (poly-SiCx) via PECVD to improve the doping concentration (glas flows, multilayer approach)
ii. investigate and optimize the interplay of annealing temperature, hydrogenation and doping on the passivation quality of PECVD-deposited poly-SiCx layers on textured c-Si substrates
iii. characterize the microstructure and composition of developed materials with modern tools (FTIR, Raman, XPS, SIMS, XRD, TEM, et al.)
iv. test the most promising passivating contacts at solar cell level, which includes the design, preparation and optimization of devices with different architectures: (i) front back contacted (FBC) with front or rear junction and (i) bi-facial solar cells with the above mentioned structure.

Available from	September 2019
Type	Experimental
Internal/External	Internal

Title **Development of silicon heterojunction (SHJ) solar cells with novel carrier selective contacts**

Daily Supervisor(s) Dr. Luana Mazzarella (l.mazzarella@tudelft.nl) and Dr. Paul Procel (p.a.procelmoya@tudelft.nl)

Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)

Short description

Silicon heterojunction (SHJ) solar cells are attractive due to their high efficiency potential combined with a lean and cost-effective production processes at low-temperature (<250ºC)
The SHJ device concept benefits from very low surface recombination velocities, which are achieved by growing intrinsic hydrogenated amorphous silicon (a-Si:H) layers on both sides of the crystalline silicon wafer by PECVD allowing very high open circuit voltages of 750 mV. Recently, record conversion efficiencies have been demonstrated for such devices with 25% for a front back contacted (FBC) and 26.6% with all-back contacted (IBC) scheme.
The aim of this project is to optimize new carrier selective contacts (CSCs) to reduce the parasitic light absorption in the front contact and carrier collection at contact interfaces with the following approaches: (i) Hydrogenated nanocrystalline silicon alloys deposited via PECVD or (ii) doping free metal oxides material, for example, MoO_3, TiO_2, ZnO, In_2O_3… prepared by thermal evaporation, or Atomic Layer Deposition (ALD).
The project intended to optimize at material level both passivation and opto-electronic performances of the CSC in stack with the (i)a-Si:H layer. The most promising CSCs will be tested on device level which includes the design, preparation and optimization of devices with different architectures (i) front back contacted (FBC) solar cells with front or rear junction, (iii) bi-facial solar and (ii) interdigitated back contacted (IBC) solar cells.

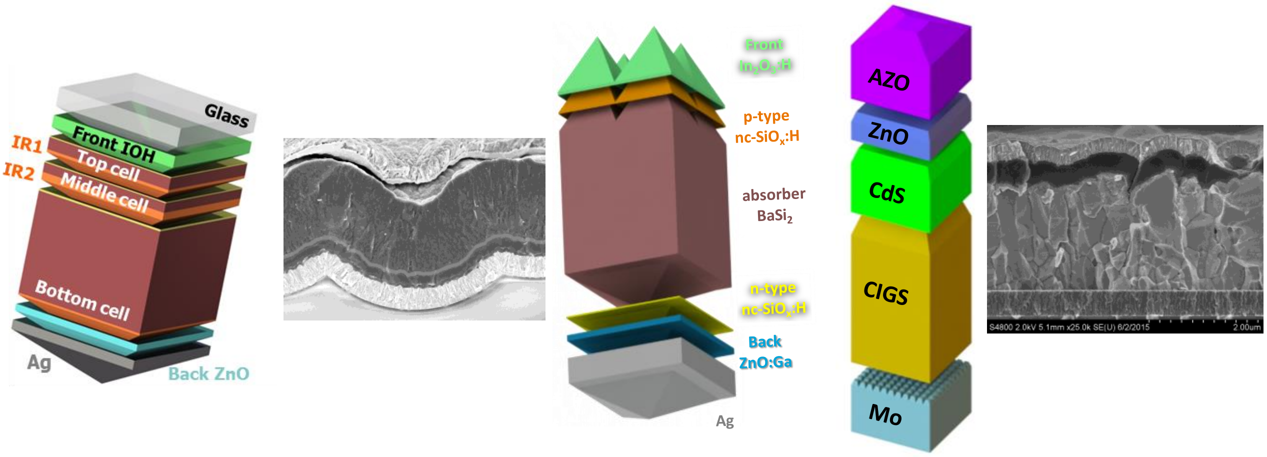
Available from	September 2019

Type	Experimental
Internal/External	Internal

Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 2nd of April 2019

Area #2: Thin-film solar cells



Title	**Development of novel low bandgap material based on a-GeSn:H**
Daily Supervisor(s)	Thierry de Vrijer (T.deVrijer@tudelft.nl)
Supervisor	Prof. Dr. Arno Smets (a.h.m.smets@tudelft.nl)
Short description	An innovative approach in the DISCO project is that the solar spectrum (0.67-1.12 V) below the silicon band gap will be used as well, which will give an additional 0.2-0.4 V to achieve ground breaking STF conversion efficiencies and high control of the product selectivity. A low band gap thin-film PV junction based on a-GeSn:H using plasma enhanced chemical vapour deposition (PECVD) will be developed. A great advantage of such a bottom cell is that it will never be current limiting, in a device with 3-5 junctions, since a sufficient number of photons are present in the infrared spectral part (0.67-1.12 V) to generate an additional 20 $mAcm^{-2}$. The bottom junction will also not limit the FF of the total PV component due to this abundance of current density available in the bottom cell. This allows the a-GeSn:H material to have a higher defect density in reference to the other junctions. The research objective of this project is to be the first to develop the a-GeSn:H absorber material. The project will consist of a thorough investigation of the full space of deposition parameters and their influence on the material properties. A range of the most promising absorbers will be used in a pin superstrate solar cell, to investigate the influence of the absorber on the device characteristics.
Available from	April 2019
Type	Experimental
Internal/External	Internal

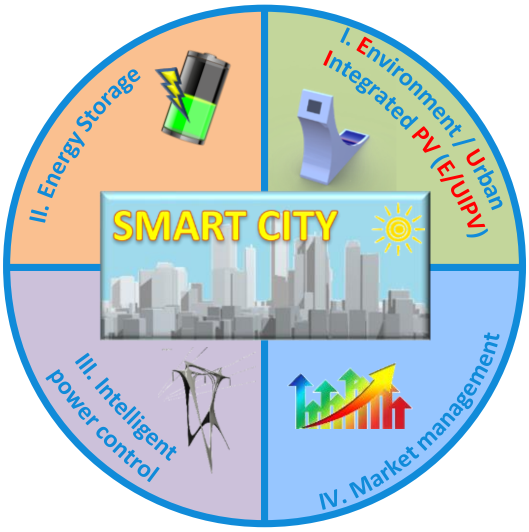
Title	**Development of 3J/4J crystalline silicon/thin film silicon devices**
Daily Supervisor(s)	Thierry de Vrijer (T.deVrijer@tudelft.nl)
Supervisor	Prof. Dr. Arno Smets (a.h.m.smets@tudelft.nl)
Short description	In the DISCO project we want to tackle the challenge of creating a large enough voltage from solar energy to simultaneously drive the CO_2 reduction reaction and oxygen evolution reactions in an integrated solar to fuel device. By growing multiple photovoltaic junctions on top of each other a high voltage device can be processed. Uniquely, in the DISCO project we focus on combining thin-film silicon (TF Si) and wafer based crystalline silicon (c-Si) technologies to create a multijunction photovoltaic device. The goal of this project is to optimize the performance of a 3J/4J hybrid c-Si/thin film silicon device. The project consists of two research objectives. The first objective focusses on the interfaces in the multijunction device. Interface engineering between separate junctions in a multijunction device is of utmost importance for a high Voc-Fill factor product. The second objective considers the light management of the multijunction device. To that end, state of the art

	surface texturing procedures, TCO's and anti-reflective coatings can be considered to maximize the light coupling into the device.
Available from	May 2019
Type	Experimental
Internal/External	Internal

Area #3: Silicon/Air batteries

Title	**Silicon-air battery**
Daily Supervisor(s)	Dr. Grégory Pandraud (g.pandraud@tudelft.nl)/ Dr. René van Swaaij(R.A.C.M.M.vanSwaaij@tudelft.nl)
Supervisor	Dr. René van Swaaij(R.A.C.M.M.vanSwaaij@tudelft.nl)
Short description	Storage of electrical energy is needed in order to mitigate the intermittent nature of renewable energy sources, like PV. Extensive research effort is directed towards Li-ion batteries. In this project we focus on silicon-air batteries. This technology potentially has comparable energy densities, but is based on abundant and non-toxic silicon. This project will focus primarily on realizing experimental silicon-air batteries and study some of the limitations, like corrosion reactions.
Available from	September 2019
Type	Experimental
Internal/External	Internal

Area #4: Environment / Urban Integrated PV systems



As mankind population grows, providing with energy, water and food is among the ten top challenges for next 50 years[1]. The share of electricity in the total energy mix will increase in future and this trend is particularly valid for cities and urban areas. Today electricity networks are mostly mono-directional with power flux being transported and distributed from a central power station (gas, coal, nuclear) to the end users. However, a significant transition in energy mix from the fossil fuels to renewable energy sources is recently ongoing[2]. Such transition has a strong impact on electricity networks that must be re-designed to allow a high penetration of electricity generated from renewable sources, such as solar and wind energy. In these novel networks, often called *Smart Grids*, power flux flows in two directions, from and to the consumer, since the consumer can generate electricity and use it on site or feed it to the grid. This new electricity infrastructure will be implemented in present and future urban areas making them smart too. The main pillars of the future electricity infrastructure in cities will be (i) grid-connected environment / urban integrated photovoltaics (E/UIPV), (ii) energy storage, (iii) intelligent power control and (iv) market management.
The ESE department possesses such expertise and the PVMD group focusses especially on EIPV. The notion of EIPV systems includes not only classical low environmental-impact built-added PV (BAPV) and modern building integrated PV (BIPV) systems but also those PV systems that are incorporated both aesthetically and functionally in the place of installation. These can be flexibly-expandable modular systems, designed to exhibit both very high yearly energy autarky (self-consumption) and/or very yearly energy yield.

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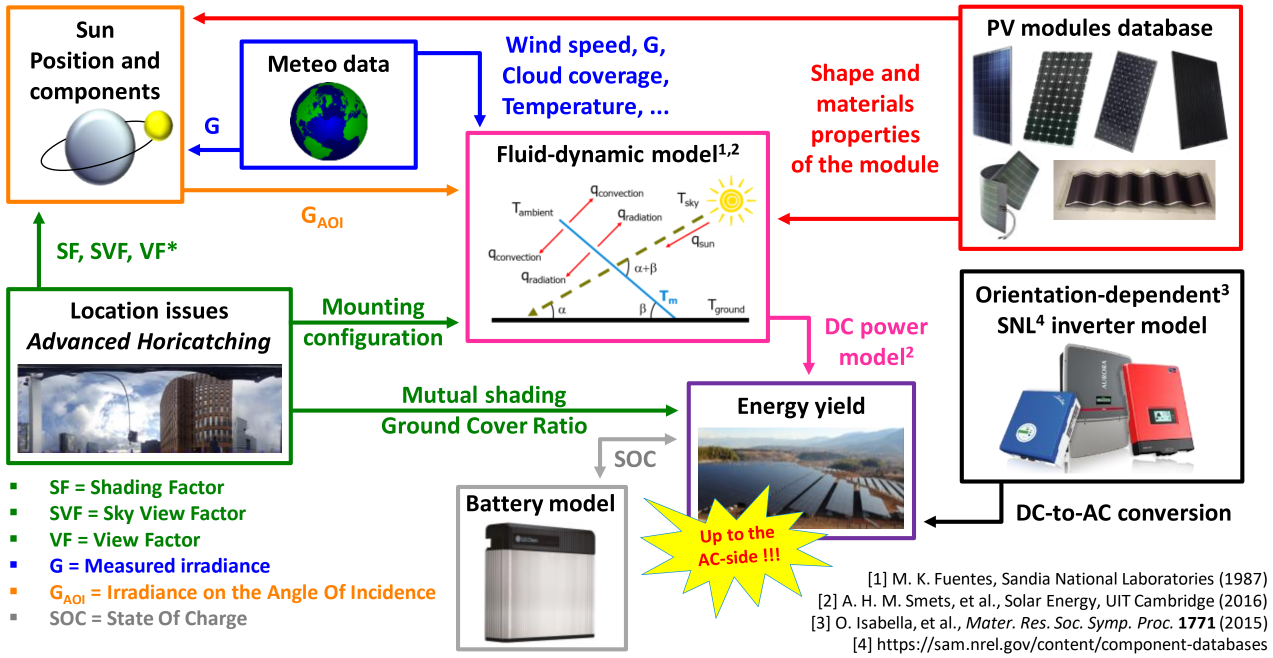
[1] Prof. R. E. Smalley (Rice University), the 27th Illinois Junior Science & Humanities Symposium (2005).
[2] Prof. E. J. Moniz (MIT) Lecture at Delft University of Technology (2010).

Scientific concepts underlying the proposals here proposed are confidential until completion of the project.

Updated list – 2nd of April 2019

The PVMD group is active in the R&D of a comprehensive energy yield modelling (i.e. from DC side to AC side) of customized PV systems as indicated in the flow chart below.



Title	**PV modules with low break-down voltage solar cells for higher energy yields in urban applications**
Daily Supervisor(s)	Andres Calcabrini
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	The forward characteristics of a solar cell define the conversion efficiency of the device. In this respect, the reverse characteristics (i.e., the dominating breakdown processes and the breakdown voltage) are not that relevant. However, when cell are connected to build a solar module that will be installed in a particular location, the reverse characteristics of the solar cells can have an important effect on the electrical and thermal performance of the PV module. Most conventional front-back contacted crystalline silicon solar cells present a high reverse breakdown voltage and PV modules made with these cells require bypass diodes to prevent hotspots and improve the module's performance under partial shading. Some other solar cells designs, present a different behaviour in reverse bias and can be used to build more shade tolerant PV modules. The goal of this project is to investigate how the electrical and thermal characteristics of the break-down behaviour of solar cells affect the DC energy yield of a PV module in an urban landscape with high levels of partial shading. The project involves the simulation of electrical circuits (PSpice/Simulink) as well as the fabrication and testing of PV modules with different types of solar cells.
Available from	Immediately
Type	Modelling/Experimental
Internal/External	Internal

Title	**Energy harvesting for outdoors PV-powered wireless sensors**
Daily Supervisor(s)	Andres Calcabrini
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Nowadays, there is a wide portfolio of commercially available low-power sensors that allows us to monitor different variables such as ambient temperature, humidity, atmospheric pressure and irradiance. These sensors can be integrated in low-cost devices both for indoors and outdoors applications. Photovoltaic technology and batteries can be used to harvest and store the energy

	required to power these sensors allowing to create robust sensing networks with energetically autonomous nodes. The goal of this project is to design, model and fabricate a small PV powered wireless sensor unit to monitor temperature and irradiance for outdoors applications. The student will design and manufacture the PV modules and the electronics required to harvest the generated electricity. Simulations must be performed to find the optimum design and minimize the required storage capacity.
Available from	October 2019
Type	Modelling/Experimental
Internal/External	Internal

Title	**Design and fabrication of optimized mini modules**
Daily Supervisor(s)	Andres Calcabrini
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	The design of PV modules must be optimized to maximize the output power. When solar cells are interconnected and later laminated to make a PV module the trade-off between optical gains and electrical losses determines the cell to module power ratio. In recent years, it has been demonstrated that it is possible to manufacture PV modules with a cell to module power ratio larger than 1, namely solar panels than can produce more power than the solar cells before the lamination. The goal of this thesis project is to optimize the in-house PV module manufacture process. To this purpose, optical and electrical simulations will be performed to characterize the materials and methods used in the module manufacturing process. The project involves the fabrication of PV module with an optimized cell to module ratio.
Available from	Immediately
Type	Modelling/Experimental
Internal/External	Internal

Title	**Foldable solar cells modules fabricated using wafer level thin film encapsulation**
Daily Supervisor(s)	Dr. Grégory Pandraud (g.pandraud@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Photovoltaic (PV) devices on flexible substrates have recently been attracting increasing attention owing to their potential applications in bendable electronic systems. Recent work has been focusing on encapsulating thin-film PVs. However, the efficiency of those modules is still lower than those of crystalline silicon solar cells. New encapsulation using flexible crystalline Si PV modules must be investigated to further developed this market segment. However, beside the foldability the encapsulation should ensure that module performances are maintained over time and against environmental effects. In this thesis we propose to **study a multilayer structure composed of polyimide and metal layers.** The foldability will be provided between the PV cell islands by removing Si. All PVs being commonly contacted via the flexible substrate.
Available from	April 2019
Type	Experimental
Internal/External	Internal

Title	**Multi-barrier thin film encapsulation using alternate SiO_2 and parylene for flexible solar cells.**
Daily Supervisor(s)	Dr. Grégory Pandraud (g.pandraud@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Photovoltaic (PV) devices on flexible substrates have recently been attracting increasing attention owing to their potential applications in bendable electronic systems. The most common encapsulant material for flexible PV modules is ethylene-vinyl acetate (EVA), which has been widely used as a standard for silicon wafer and glass thin-film PV modules. However, EVA has some serious drawbacks that adversely influence module performance (e.g. delamination, reduced adhesion). These problems may be exacerbated by the substrate

bending-induced stress in flexible thin-film PV modules, which impairs mechanical functions and facilitates the ingress of moisture. New encapsulation for flexible thin-film PV modules must be developed to ensure that module performances are maintained over time and against environmental effects. In this thesis we propose to **study a multilayer structure composed of parylene and SiO_2 layers.**
All the materials development and solar cell fabrication will be done in the cleanroom.

Available from April 2019
Type Experimental
Internal/External Internal

Title **Novel and industrially applicable cooling element for photovoltaic modules**
Daily Supervisor(s) Hesan Ziar (h.ziar@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description One of the main factors that affect photovoltaic (PV) module performance is temperature. Rising temperature reduces efficiency and causes aging. Cooler PV modules will live longer leading to more energy yield during their life time. PV industry is now considering novel and industrially applicable approaches to keep modules working temperature low. One of the possible approaches is intelligent design of a passive heat sink element that can maximize heat dissipation, distribute the temperature gradient smoothly over the its surface and reduce the chance of hot-spot formation. Such an element will be design, and optimized through multi-physics simulation using COMSOL software package. The design objective functions are minimizing material use and maximizing heat dissipation. Further the cooling element will be tested at the PVMD monitoring station to see its real-world performance. This will include module's electrical performance measurement and infra-red thermal imaging for further optimization and TRL (technology readiness level) increase.
The project is further broken down into following sections:
1- Preliminary research and literature review;
2- Acquaintance with COMSOL software package;
3- PV cooling element design and optimization;
4- Prototyping the design;
5- Experimental tests at PVMD monitoring station and trouble shouting;
6- Reporting.
Background in mechanical engineering or physics along with experience with COMSOL would accelerate the project progress.

Available from April 2019
Type Theoretical/Experimental
Internal/External Internal

Title **Urban photovoltaic installation map for districts in Dutch cities**
Daily Supervisor(s) Hesan Ziar (h.ziar@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description Price of photovoltaic (PV) is decreasing drastically and it is being utilized more and more in urban areas to keep the load and source in electrical grid as close as possible. Thus, the need for PV integration into urban areas is increasing. On the other hand, since in urban areas geometry is not simple, it is rather difficult to find the sweet spots that capture the most out of the sun light. On top of that, the low voltage grid infrastructure in urban areas do not always have enough capacities to handle the future urban PV power generation. Therefore, first we need to know what locations are good enough to receive sunlight energy and then, whether the local grid at those locations is capable of accepting that amount of energy flow. This means that we need two maps to direct us to the best location for PV installation. Therefore, this project has two main parts. First part is to use PVMD's already developed model for irradiation estimation in an urban district (irradiation map). The second part is to overlay the obtained irradiation map with a low voltage grid map (electrical map) to pinpoint the best PV installation spots and bottlenecks. This study will be done for at least one district in Amsterdam (or any other Dutch city based on data availability).
The project is further broken down into following sections:

1- Preliminary research about PV, Lidar data and low voltage grid;
2- Acquaintancy with MATLAB, GIS, and ETAP software packages;
3- Extract the Roof-top PV potential map for the selected district;
4- Overlay the Roof-top PV potential map with the low voltage grid infrastructure;
5- Analysis of the map and pinpoint sweet spots and bottlenecks for PV installation;
6- Reporting.

Background in electrical engineering along with basic experience with MATLAB, GIS, and ETAP would accelerate the project progress.

Available from April 2019
Type Modeling
Internal/External Internal

Title **Floating bifacial photovoltaic systems with and without reflectors**
Daily Supervisor(s) Hesan Ziar (h.ziar@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description The demand for clean energy is constantly increasing, and the development of ways to utilize PV technology is becoming ever faster. However, the cost are still relatively high and the availability of the surface area for the PV systems is limited in the Dutch urban area. To make a smart use of available space, project INNOZOWA which stands for INNOvatieve ZOn-pv at Water has been started. In a consortium of four parties, PVMD is contributing to building a revolutionary way of generating solar energy on in-land water.

The aim of this MSc project is to monitor the energy production of various pilot mono-facial and bifacial PV systems (with and without reflectors) installed at Weurt and compare them with the PVMD modeling toolbox. To reach this goal, first the candidate should include DC-to-AC power conversion unit to the already available PVMD toolbox (MATLAB script). This MATLAB script will be an important piece of PVMD's modelling toolbox. Next step is to make remote connection to the inverters at the PV installation and fetch the data remotely and upload it to a LAMP server at TU delft (The platform is already available). The final step is to model the PV systems in PVMD toolbox and compare the measured and model values and providing suggestions for model and installation improvement.

It takes a team to build a dream! That's our motto in the novel project of INNOZOWA. For more information please check https://innozowa.nl.

Available from April 2019
Type Modeling/Experiment
Internal/External Internal

Title **Contactless photovoltaic cell power transfer**
Daily Supervisor(s) Hesan Ziar (h.ziar@tudelft.nl)
Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description One of the main reasons of the efficiency drop from cell to module is conduction loss. Metallic bars and junctions that convey electrons from PV cells to the terminals of the module cause energy loss. If the charge carriers produced in the semiconductor material are transferred to the PV module terminals with minimum conduction loss, the efficiency of the PV module will increase. In this research, we are seeking for efficient ways to incorporate wireless power transfer (WPT) techniques into PV cell/module architecture. A broad theoretical study is required to comprehend how WPT techniques can be incorporated into PV cell or module. And whether these technique in theory and practice would be more efficient than the direct-contact approach. The work will be carried out theoretically and then by simulation. At the end, the MSc student will make suggestions on the best design approach as a guideline for near future prototyping.

The project is further broken down into following sections:

1- Literature study about PV and Wireless power transfer techniques;
2- Simulating the wireless power transfer techniques for typical PV cells and modules;
3-Calculating the theoretical and practical power transfer efficiency for PV cell/module application and comparison with direct-contact power transfer approach;
4- Detailed guideline for prototyping;

5- Reporting;
Background in electrical/electronic engineering and basic knowledge of semi-conductor physics along with experience with MATLAB/Simulink, would accelerate the project progress.

Available from	April 2019
Type	Theoretical/Modelling
Internal/External	Internal

Title **Photovoltaic applications in LiFi**

Daily Supervisor(s) Hesan Ziar (h.ziar@tudelft.nl)

Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl)

Short description light-fidelity (LiFi), also called visible light communication (VLC), has recently gained huge interest. In such a communication system, an optical sensor translates the received luminous modulation flux into an electrical signal which is further decoded. To consider LiFi as an alternative solution for wireless communication, the receiver must be operational in both indoor and outdoor conditions. PV cells could appear as a solution to this issue. However, since LiFi is a very new technology, there are several questions that still need solid answers before incorporating PV cells into LiFi communications systems. This MSc project is based on theoretical research and investigation and at the end of the thesis the following questions are expected to be answered:

- Using PV cell as the receiver in LiFi system, what PV technology serves the best?
- What is the optimum thickness and size for PV LiFi receiver?
- What is the communication efficiency and SNR (signal to noise ratio) response for PV LiFi receiver?
- What is the maximum achievable data rate (with respect to distance and light level) for this application?
- In general, what are the advantage and disadvantages of integrating PV in LiFi?

The project is further broken down into following sections:
1- Deep research on PV cells and LiFi communication technology;
2- Theoretical study of PV integrated LiFi communication system;
3- Designing experiments to test the claims raised in the research (conducting the experiments depends on the project progress and their feasibility);
4- Reporting.
Background in communication engineering or physics would accelerate the project progress.

Available from	April 2019
Type	Theoretical/Modeling
Internal/External	Internal

Title **Application of cloud resolving models in photovoltaic yield prediction**

Daily Supervisor(s) Hesan Ziar (h.ziar@tudelft.nl)

Supervisor Dr. Olindo Isabella (o.isabella@tudelft.nl), Dr. Stephan de Roode (S.R.deRoode@tudelft.nl)

Short description Clouds passing over PV plants causes the energy production to drop. Knowing cloud coverage with high resolution will give valuable information about photovoltaic power production. Using meteorological data from Royal Netherlands Meteorological Institute (KNMI), it is possible to run cloud-resolving models and obtain cloud coverage for any arbitrary location in the Netherlands. This technique can be well integrated into PV yield forecasting approaches. The benefit of such a combination is that instantaneous power production for PV plant (over a region) can be predicted beforehand and necessary dispatching action can be done. If the result of this research be satisfying, then in the near future, when the share of PV power production in electrical grid increases, this approach could be helpful for proper electrical power dispatching and battery charging/discharging algorithms.
The project is further broken down into following sections:
1- Literature review on PV system yield modelling and cloud-resolving models;
2-Verfying cloud-resolving model outcome using sky camera data of PVMD monitoring station;

3- Simulating irradiation components and PV system yield at specific locations using cloud-resolving model outcome;
4- Verifying modeled irradiation components and PV system yield predictions using measured data from PVMD monitoring station and roof-top PV systems;
5- Suggestion for model improvement and reporting.
Background in physics or meteorology would accelerate the project progress.

Available from	April 2019
Type	Modeling/Experiment
Internal/External	Internal-Joint Project between PVMD and Faculty of Civil Engineering and Geosciences

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Title	**Manufacturing and long-term measurements of multi-functional PV elements**
Daily Supervisor(s)	Juan Camilo Ortiz Lizcano(J.C.OrtizLizcano@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Integration of Photovoltaic (PV) systems within our urban environment demand a multi-functional approach. PV modules are not only required to produce electrical energy, they must be able to function as a building, car, road or any other urban envelope. For this reason, aesthetic versatility and thermal management are now considered essential on any PV product oriented towards an integrated use. In this thesis the student is required to manufactured coloured modules, thermal management solutions (like PDLC and IR filtering filters) coupled with PV capabilities, and perform long term measurements to study their potential. Modelling phase fort these solutions has already been created, and the work will focus mainly on the validation of such models and improvements required based on the experimental data gather within several months
Available from	November 2019
Type	Experimental
Internal/External	Internal

Title	**Manufacturing of Photovoltaic Mini-modules with different effective area**
Daily Supervisor(s)	Juan Camilo Ortiz Lizcano(J.C.OrtizLizcano@tudelft.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Solar Canopy and façades are gaining a lot of interest lately. Good aesthetics and efficiency are among the most important aspects for glass/glass PV modules based on c-Si solar cells. Aesthetics on these modules are limited by the standard size of solar cells currently available in the market (5 in x 5 in and 6 in x 6 in). In this thesis, standard solar cells will be laser-cut to produce glass / glass modules with different cell distribution. The student is required to design and manufacture mini-modules (up to 60 cm x 60 cm) with different cell spacing, distribution patterns, colours and interconnection schemes such that aesthetic versatility is achieved with an optimized performance.
Available from	November 2019
Type	Experimental
Internal/External	Internal

Area #5: Projects with external partners

Title	**Predicting the Photovoltaic Output of Residential Solar Systems in the Netherlands using a machine learning approach**
Daily Supervisor(s)	ir. Jaap Donker (jaap@solarmonkey.nl)
Supervisor	Dr. Olindo Isabella (o.isabella@tudelft.nl)
Short description	Currently, Solar Monkey is using an analytical approach for modelling yield of pv systems. In the past years, many systems have been monitored. The data generated from these systems may prove useful in predicting the performance of similar systems through a machine learning approach. The objective of this research is to analyse ML algorithms' performance on predicting the performance of individual systems, using the monitoring data as training data.
Available from	April 2019
Type	Modelling
Internal/External	External

Title	**4T solar cells based on a-Si:H and CIGS solar cells**
Daily Supervisor(s)	Dr. René van Swaaij(R.A.C.M.M.vanSwaaij@tudelft.nl)
Supervisor	Dr. René van Swaaij(R.A.C.M.M.vanSwaaij@tudelft.nl)
Short description	In order to improve the performance of solar cells, spectral losses need to be minimized. An effective way of realizing this is by tandem solar cell structures in which different component solar cells are tailored to a specific part of the solar spectrum. Often these tandem solar cells are made in series, which implies that current matching is required. Current matching is often hard to realize. In a 4-terminal (4T) solar cell current matching is not required, as each component cell has its own terminals. In this project a 4T approach will be investigated based on an a-Si:H solar cell and CIGS bottom solar cell. Important aspect is the optical structure of the entire 4T solar cell, which will be investigated by means of optical simulations.
Available from	September 2019
Type	Experimental
Internal/External	Internal/cooperation with Solliance
