<u>EU PV Clusters and Scalenano Workshop</u>
<u>Meeting minutes</u>

Date: 17 and 18 September 2014

Place: Cadarache (France)

Participants:
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David Gutierrez (LEITAT)
Fabrice Stassin (EMIRI)
Paula Queipo (Nanofuture)
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Cedric Broussillou (NEXCIS)
Veronica Bermudez (EDF)
Simon Perraud (CEA)
Bertrand Fillon (CEA)

- **<u>Introduction and objectives of the workshop</u>** (Bertrand Fillon)
    - The objective of the workshop is to align and consolidate the roadmaps and priorities identified by the EU PV Clusters, NANOfutures, Solarrok and EMIRI, in the field of photovoltaics. This workshop is supported by the European Commission through the SCALENANO project.
    - Another objective is to propose 3 calls for projects, based on the prioritization of the topics.
- **<u>Presentation of the EU PV Clusters</u>** (Bertrand Fillon)
    - The EU PV Clusters gather 84 projects supported by the European Commission in the field of photovoltaics. The projects have been classified into clusters addressing

specific photovoltaic technologies or cross-cutting activities. More information can be found on the EU PV Clusters website (www.eupvclusters.eu). According to the latest information, the number of projects in each cluster is the following:

    - Cluster n°1: bulk crystalline silicon solar cells: 5 projects
    - Cluster n°2: thin film solar cells: 19 projects
    - Cluster n°3: organic photovoltaics (OPV) and advanced concepts (including nanotechnologies for photovoltaics): 36 projects
    - Cluster n°4: concentrated photovoltaics (CPV): 6 projects
    - Cluster 5: installations and grids: 5 projects
    - Cluster 6: production tools and processes: 3 projects
    - Cluster 7: industry support: 10 projects

- Two workshops have been recently organized by the EU PV Clusters, with the support of the European Commission and the SCALENANO project, in order to identify the main bottlenecks in the field of photovoltaics: one workshop was held in 2013 in Barcelona, and another in 2014 in Athens (during the "Industrial Technologies 2014" event).
- The bottlenecks identified during those two workshops were the following:
    - Cluster n°1:
        - Reducing material layer thickness and keeping high efficiency
        - Surface texturing to optimize light capture
        - Encapsulation process and high barrier properties
        - Developing and applying advanced characterization methods, especially suited for ultra-thin Si solar cells, e.g. as light trapping becomes more important better methods for quantifying light trapping need to be developed
        - Development of a comprehensive model for the impact on material quality of impurities and defects during processing
        - Research on silicon production and purification technologies able to reduce cost and maintain quality by increased productivity and reduced energy consumption. New and improved technologies for feedstock production through silane decomposition (mono- and chlorosilane) as well as through the upgraded metallurgical route needs to be developed.
        - Improvement of seeded growth for high-performance mono and multi-crystalline silicon material
        - Development of ultra-thin (< 100 um), kerfloss-free wafers, e.g. by the lift-off technique
        - Development of better reliability and accelerated ageing tests for the new device architectures such as PERC, IBC, ... since standard IEC tests of today are not sufficient for these new technologies
        - Development of ultra-high efficiency Si-based cells, such as tandem cells with Si wafer bottom cell, and novel light management approaches such as spectral splitting, up- and down conversion, photonic back reflectors, ...
    - Cluster n°2:
        - Material is the main bottleneck
        - Understanding the behavior at the structure level and at the interfaces
        - Surface texturing to optimize light capture
        - Improving TCO properties or ITO replacement
        - Encapsulation process and high barrier properties

                - Reducing material layer thickness and keeping high efficiency
                - Developing and applying advanced characterization methods
                - Modeling heterostructures
                - High productivity deposition technologies with reliability
                - Reducing emphasis on increasing cell and module efficiency, better understanding the needs of specific applications. Matching bulk silicon efficiencies is not essential if other functionalities are offered (optical transparency, mechanical flexibility, high level of integration, etc.)
            - Cluster n°3:
                - High productivity deposition technologies with reliability
                - Studies from basic research to technological research are necessary
                - Reproducibility of scale-up stage
                - Modeling heterostructures
                - Developing and applying advanced characterization methods
            - Cluster n°4:
                - Reliability , reproducibility, durability of the process
            - Cluster n°5:
                - Need of technological projects with wider field of application, not necessarily at low cost or high efficiency
            - Cluster n°6:
                - Quality control and standard
            - Cluster n°7:
                - More involvement of end users (solar designers, architects, …)
                - Mismatch between the targets of the PV industry and the needs of key user sectors (e.g., BIPV)
                - Involvement of all value chain partners in the projects at high TRL

- **NANOfutures roadmap** (Paula Queipo)
    - NANOfutures is an European integration and innovation platform. NANOfutures is open to countries outside Europe. It crosses the bridge from the knowledge to the market. NANOfutures gathers 926 stakeholders from 57 countries.
    - The NANOfuture roadmap is based on a value chain (VC) approach, with technical and non-technical actions. The full roadmap can be found here: http://www.nanofutures.eu/sites/default/files/NANOfutures_Roadmap%20july%202012_0.pdf
    - In the case of photovoltaics, the relevant value chains in the NANOfutures roadmap are (see **figure 1**):
        - VC1: lightweight multifunctional materials and sustainable composites
        - VC3: structured surfaces
        - VC4: alloys, ceramics, intermetallics
        - VC6: integration of nano
    - The Value4nano project objectives are:
        - development and completion of 4 selected value chains
            - nano and micro printing for industrial manufacturing
            - nano-enabled surfaces
            - manufacturing of powders made of functional alloys, ceramics and intermetallic
            - lightweight multifunctional materials and composites for transportation
        - business modelling and planning for a set of pilot lines
        - release a short term roadmap

- analysis of the main gaps (industrial/technical, economic, societal) affecting the 4 value chains

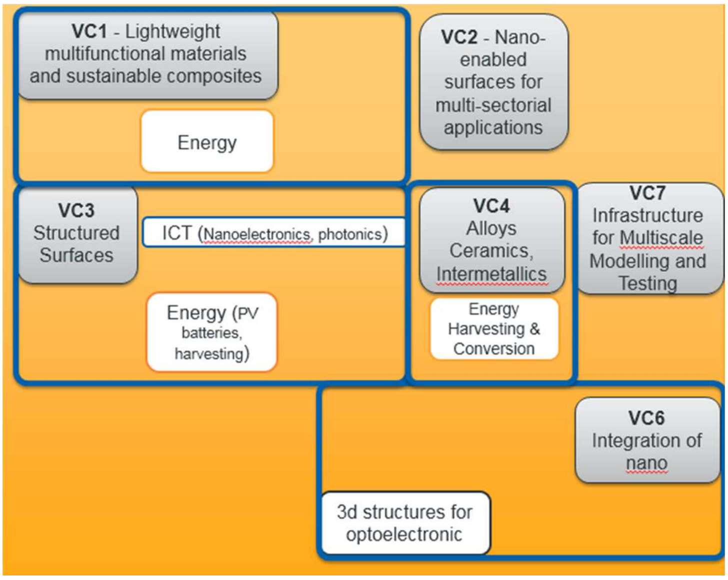

***Figure 1**. Relevant NANOfutures value chains in the case of photovoltaic applications.*

- **<u>Solarrok</u>** (Karl Knöbl)
    - The Solarrok project objective is to boost EU competitiveness in PV. The consortium gathers Research centers, Cluster management, Regional authority, Support. An analysis of current capacities in seven PV regions was performed and research priorities were identified.
    - The whole PV value chain was analyzed by the Solarrok project. A survey of future needs for research capacities, with inputs from both research institutes and companies, was performed, for
        - crystalline silicon (see **figure 3a**)
        - thin films (see **figure 3b**)
        - BOS components (see **figure 3c**)
    - Joint actions on generic activities were also identified.

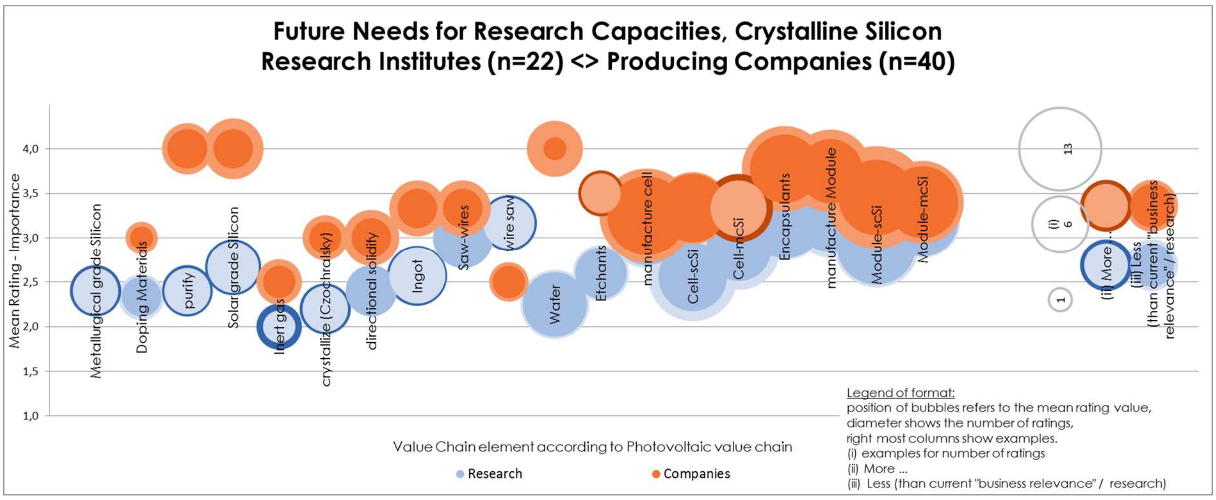

***Figure 3a**. Outputs of Solarrok project: future needs for research capacities for crystalline silicon technologies.*

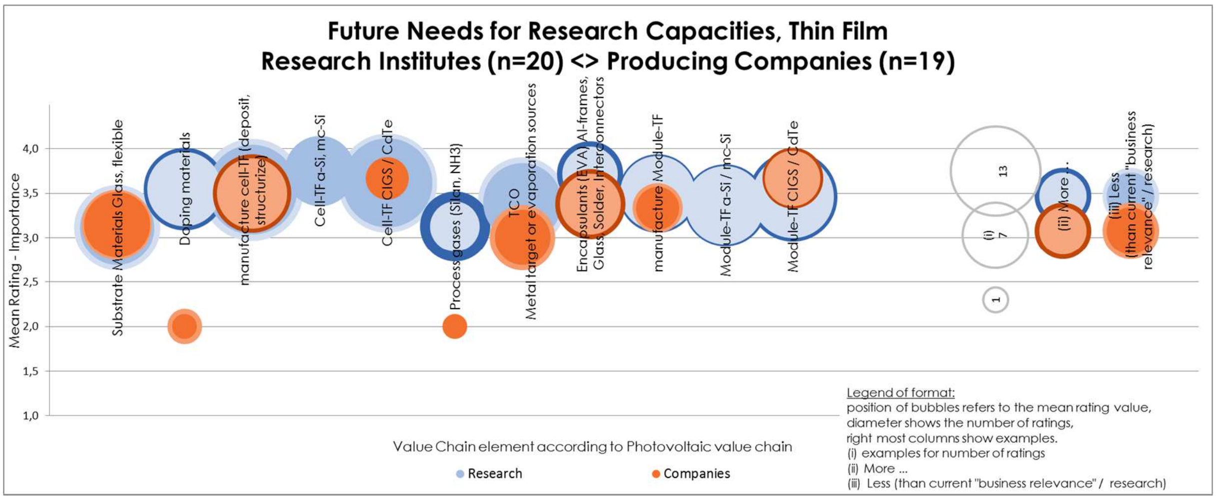

***Figure 3b**. Outputs of Solarrok project: future needs for research capacities for thin film technologies.*

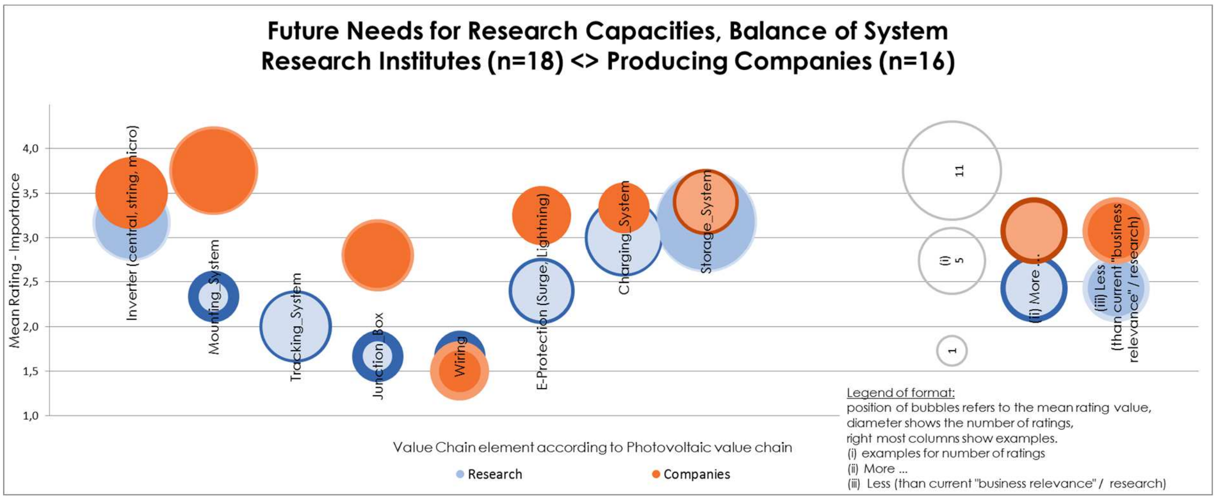

***Figure 3c**. Outputs of Solarrok project: future needs for research capacities for balance of system.*

- **EMIRI** (Fabrice Stassin)
  - EMIRI is an organization focused on advanced materials across multiple energy technologies. EMIRI is industry oriented (from the lab to the market). The typical technology readiness levels are from 4 to 7.
  - EMIRI provided in 2013 a first wave of priorities for future R&I. 12 orientations were identified, that must be justified by a business rationale in Europe
    - Energy efficiency
    - Renewable electricity
    - Energy system integration
    - etc.
  - Among those 12 orientations, 3 orientations deals specifically with photovoltaics (see **figure 4**):
    - Sub-topic (ST) 1.2: advanced materials & new deposition processes for BIPV
    - ST 2.3: advanced materials and processes for high yield, large scale manufacturing of solar energy harvesting systems
    - ST 2.4: advanced materials and processes for high efficiency solar energy harvesting

Sub-topic 1.2 – Advanced Materials & new deposition processes for building-integrated photovoltaics (BIPV)

To enable market penetration of BIPV, a drastic decrease in manufacturing costs is needed and is possible by addressing the high integration cost of PV components imported from the standard PV roof market and the complex flow typical of "make-to-size" production. Emerging technologies such as organic photovoltaics (OPV) and dye-sensitized solar cells (DSSC) open up the possibility to deposit the PV functional layers directly on the final substrate potentially leading to lower integration costs and "cuttability". Where transparency is not needed, focus should be on improving the PV efficiency of current or associated technologies.

Sub-topic 2.3 – Advanced Materials and processes for high yield, large scale manufacturing of solar energy harvesting systems (PV, CSP)

Competitive solar energy generation requires a reduction in the levelized cost of energy (LCOE) for photovoltaic (PV) and concentrated solar thermal (CSP) energy harvesting systems. Advanced materials and associated manufacturing processes are key enablers of cost reduction and new functional materials (particles, thin films, multiphase materials) for lower cost consumables and lower costs manufacturing processes shall be developed. These new materials and processes will allow the European advanced materials and high-end equipment supply sectors to keep on adding value to their products and maintain or even grow their industrial leadership.

Sub-topic 2.4 – Advanced Materials and processes for high efficiency solar energy harvesting (PV, CSP)

Advanced materials and processes enabling a significant increase in the efficiency of PV, CSP systems are also needed to make solar energy generation more competitive. New functional materials and materials combinations (multilayers, composites, smart surfaces, encapsulants, ...) can drastically enhance the efficiency beyond that of current technologies. These materials to be developed will also need to enable durability and reliability of the new PV, CSP technologies.

***Figure 4**. EMIRI R&I orientations relevant to photovoltaics.*

- **<u>1st approach for alignment of roadmaps and priorities</u>** (all workshop participants):
  - In a first approach for alignment of roadmaps and priorities, the EU PV Clusters needs were linked to photovoltaic application challenges (KPI related) and the fit with NANOfutures and EMIRI priorities were highlighted (see **figure 5**).

Application Challenges (KPI-related)	EU PV cluster needs and bottlenecks to tackle these challenges	Spill-overs	Fit with NANOFUTURES	"Bubble name"	Fit with EU PV Clusters	Fit with EMIRI
Efficiency improvements (W/m2)	Materials enabling new device architectures / PV concepts (focus on absorption layer)		VC4	VC4-001 Medium VC4-001 Short VC4-001 Long	Cluster 1, 2, 3	ST 1.2 ST 2.4
	(Nano)structured surfaces to optimize light capture		VC1	VC1-014 Medium VC1-012 Long	Cluster 1, 2, 3	ST 2.4
	Materials for novel light management approaches		VC1	VC1-014 Medium VC1-012 Long	Cluster 1, 2, 3	ST 2.4
	Materials for more efficient TCO layers		VC1	VC1-014 Medium VC1-012 Long	Cluster 2, 3	ST 2.4
	…					ST 2.4
OPEX (euro/m2)	Materials enabling thinner layers (with higher purity, facilitated conversion to absorption layer (purity, phases))		VC3		Cluster 1 (& also 2)	ST 2.3
	ITO replacement (scarcity vs cost)		VC3		Cluster 2 (& also 3)	ST 1.2 ST 2.3
	Materials enabling new deposition processes (nanoparticles, …)	Printed electronics	VC3	VC3-002-Short	Cluster 2 (& also 1, 3)	ST 1.2 ST 2.3
	…					ST 2.3
Lifetime	Multilayer barrier materials to deal with contamination, degradation of performance (encapsulants, …)	Packaging, transport	VC1	VC1-008-Short	Cluster 1, 3	ST1.2 ST 2.4
	…					
Versatility (market size)	Materials enabling higher range of applications, facilitating the integration into systems (flexibility, shaping, patterning, …)		VC3	VC3-001-Long	Cluster 2, 3	ST1.2
	…					
Cross-cutting Issues	Characterization - Modelling - Standardization of quality / performance assessment - EHS aspects		VC4 VC1	VC4-002 Long VC1-010 Long VC1-NT3-Short	All clusters	ST1.2 ST2.3 ST2.4
	Scaling up (to module level) - Processes - Chemicals, Materials, Nano enabling scaling up			VC3-002-Short VC3-003-Short/Medium	All clusters	ST1.2 ST2.3 ST2.4

***Figure 5**. Alignment of roadmap and priorities (EU PV Clusters, NANOfutures, EMIRI): first approach.*

- **2nd approach for alignment of roadmaps and priorities** (all workshop participants):
    - In a second approach for alignment of roadmaps and priorities, the research topics from NANOfutures related to photovoltaics were compared with the priorities defined by the EU PV Clusters and Solarrok, and ranked accordingly (see **figure 6**).

NANOfutures					EU PV Clusters	EU PV Clusters score	Solarrok / Crystalline Silicon	Solarrok / Thin films	Solarrok score	Total score
	Action	Short/middle/long term	Applications	Application score						
VC1: Lightweight multifunctional materials and sustainable composites	Multilayer barrier materials	ST	Energy, Packaging, Construction	3	1, 2, 3	3	Encapsulants, Modules	Substrates, Doping materials, Encapsulants, Modules	3	9
	Multilayer materials	MT	Energy, Packaging, Transportation, ICT	4	1, 2, 3	3	Cells (e.g. HIT)	Cells, Substrates (e.g. light trapping, diffusion barriers), TCOs	1	8
	Integrated multilayer materials	LT	Energy, ICT	2	1, 2, 3	3	Cells (e.g. HIT)	Cells, Substrates (e.g. light trapping, diffusion barriers), TCOs	1	6
	Control of nanolayer interfaces and adhesion	MT, LT	Energy, ICT	2	2,3	2	Cells, Modules	Cells, Substrates, TCOs, Modules (e.g. silver paste/TCO interface)	1	5
	Materials modelling, thermal simulation and process design	LT	Energy, ICT, Construction	3	1,2,3	3	Manufacture cells	Process gas, Manufacture cells deposit and structurize	1	7
VC3: Structured surfaces	2D - Printing with higher definition and higher throughput	ST	Energy, ICT, Textile, Medecine, Transport, Construction	6	1,2,3	3	Cells (e.g. screen priting of grids)		1	10
	2D - Large area metal and selective etching	ST	Energy, Textile	2	2	1	Etchants		2	5
	2D&3D - Metrology for process and functional properties analysis	MT	Energy, ICT, Textile, Medecine, Transport, Construction	6	1,2,3,6	4			0	10
	2D - Integration of technologies with increased throughput and definition	MT	Energy, ICT, Textile, Medecine	4	1,2	2		Manufacture cells deposit and structurize	2	8
VC4: Functional alloys, ceramics and intermetallics	Modelling of chemical composition size and optoelectronic properties	MT	Energy, ICT	2	1, 2, 3	3			0	5
	Modelling of the growth process and electronic and optical properties	MT	Energy, ICT	2	1, 2, 3	3		TCOs	1	6
	Integration of nanoparticles and aggregates into materials	LT	Energy, ICT	2	1, 2, 3	3			0	5
	Evaluating compatibility of new materials with existing processing steps. Intimate mixing on the nanoscale	ST	Energy, ICT	2	1, 2, 3	3	Metallurgical grade silicon		1	6
	Characterization of hosted nanoparticles and nano-aggregate	ST	Energy, ICT	2	3	1			0	3
VC6: Integration of nano	Reactive/insitu production and structure refinement	MT	Photonics, Direct manufacturing	2	3	1			0	3
	Precision large scale nano/micromanufacturing of 3D structures	LT	Photonics, Finished netshape, Direct manufacturing, Catalysis and filtration	4	1,2,3	3	Cells (e.g. light management)	Cells (e.g. light management)	1	8
	Nanomaterials electrochemical deposition, tape casting, block	MT	Photonics	1	3	1			0	2

***Figure 6**. Alignment of roadmap and priorities (EU PV Clusters, NANOfutures, Solarrok): first approach.*

- **<u>Proposition of 3 calls</u>** (all workshop participants):
    - 3 calls were proposed based on the ranking of figure 6. First drafts were prepared during the meeting and will be consolidated by the end of September.
        - Call n°1: multilayer barrier materials
        - Call n°2: non vacuum deposition processes
        - Call n°3: micro and nanomanufacturing of 3D structures, in particular for light management
- **SCALENANO: objectives and approach. Review of main achievements & discussion** (Alejandro Perez-Rodriguez)
- **SCALENANO: Visit to pilot line at NEXCIS site** (see **figure 7**)

Figure 7. *Visit to pilot line at NEXCIS site.*