ECoVEM
European Centre of Vocational Excellence in Microelectronics

Co-funded by the Erasmus+ Programme of the European Union

COURSE DATASHEET

COURSE TITLE	6.2- Manufacturing standard silicon photovoltaic (PV) cells: Theory and technological responses
COURSE PLATFORM	Moodle
COURSE WEB	ECoVEM - Programme ERASMUS+ | INES - Institut National de l'Énergie Solaire (ines-solaire.org)
ACCESS INFORMATION	On-site training. Custom-made module-based program (can be combined with courses 6.1 and 6.3). Trainees must contact INES training department through course web link in order to define the program according to their skills, needs and time availability.
PROVIDER INSTITUTION	INES Formation
PROVIDER CONTACT	*name:* *LELIEVRE J-F* *email:* jf.lelievre@ines-solaire.org
TEACHERS	*T1- LELIEVRE Jean-François* *T2-* *T3-*
TYPE OF COURSE	☐ On-line (stand-alone) ☐ On-line (tutored) ☐ Visio ☐ Work-based training ☒ On-site training ☐ Hybrid on-site/on-line ☒ Other (specify): **CEA-INES research laboratories tour + INES-PFE pedagogical platform tour**
DATES EXPECTED OPENING	06/2022
DATES AVAILABILITY	☐ 365 days accessible ☒ Other (specify): according to trainers' availabilities and trainees' demand
WORKLOAD STUDENT (in hours)	**14 to 21 (according to desired technical level)**
TYPE OF TRAINING	☐ Initial VET ☒ Continuous VET ☐ Work-based training
EQF LEVELS	☐ EQF 3 ☐ EQF 4 ☐ EQF 5 ☒ EQF 6 ☒ EQF 7 ☒ EQF 8
LANGUAGES	☒ English ☒ Others (specify): ……French……..
MAIN SUBJECT	☐ Design and manufacture of PCB ☐ Microelectronics packaging technologies ☐ Integrated circuits design ☐ System design ☐ Fundamentals of microelectronics manufacturing ☒ Microelectronics for a greener economy ☐ Key competences and skills ☐ Other (specify): ……..

COURSE DESCRIPTION	As solar photovoltaic (PV) energy will become one of main sources in the decarbonized World energy mix of next mid-century, the industrial production of PV cells should experience a tremendous growth within the next years, with part of the production being re-located in Europe. In this context, highly skilled profiles in PV are of great interest for the industrial and research sectors. This course gives in-depth knowledge of the entire industrial production chain of PV cells, from the raw material to the PV cell. It allows understanding the theory of each fabrication step of standard silicon PV cells (PERC cell) as well as the corresponding industrial processes optimized to find the balance between high efficiency and low cost. It gives also an overview of the different innovative silicon PV cell architectures as well as the future research routes for the development of large-scale PV. Cutting-edge trends in PV will be further highlighted by CEA-INES research laboratories tours showing the latest technological innovations developed on industrial-scale state-of-the-art equipment.
KEYWORDS	*KW1- Photovoltaics* *KW2- Microelectronics for photovoltaic applications* *KW3- Industrial manufacturing*
LEARNING OBJECTIVES	*LO1-* Comprehend the photovoltaic principle in details, as well as the physical and technological limitations of PV technology *LO2-* Understand the different PV cell architectures and their potential and limitations to increase PV cell efficiency, focusing on the cutting-edge trends and technological innovations in PV *LO3-* Apprehend the microelectronic principles and tools used for the optimization of the fabrication of standard and advanced PV cells
PREREQUISITES	*P1-* Basics in electricity *P2-* Basics in microelectronics *P3-* Basics in physics of materials
LEARNING OUTCOMES	*Knowledge:* *K1-* Overview of silicon PV technologies and trends *K2-* Theory and technological answers of each fabrication step of standard silicon PV cells (PERC cell) *K3-* In-depth knowledge of the entire industrial production chain, from the raw material to the PV cell
	Skills: *S1-* Advanced skills in microelectronics, materials and photovoltaics *S2-* Advanced skills in industrial and lab-scale fabrication and characterization equipment *S3-* Master the operating principle of PV, its limits and the technological solutions to improve efficiency *S4-* Understand the theory as well as the corresponding technological and industrial optimization process of the different PV cell manufacturing steps *S5-* Appreciate the different innovative architectures of silicon PV cells as well as the future research routes *S6-* Theory and applications of characterization equipment

	Responsibility and Autonomy:	*C1-* Ease with interacting with specialized experts of solar technologies *C2-* Proactivity in orienting technological solutions *C3-* Design-thinking
MODULES	*Module1*	*Title:* Understanding of the photovoltaic context
		Description: Status of the current and future energy markets PV Market and Applications
	Module2	*Title:* Production and purification of solar grade silicon
		Description: Metallurgical silicon manufacturing process and market Electronic and solar grade silicon manufacturing processes and market
	Module3	*Title:* Crystallization and sawing of solar grade silicon
		Description: Crystallography and semiconductor physics ➢ Fundamental properties of semiconductors and characteristics of silicon ➢ Silicon crystal structure and energy band diagram ➢ Absorption, photogeneration, recombination and transport of charges Industrial crystallization processes ➢ Czochralski crystallization of monocrystalline silicon ➢ Directional crystallization of multicrystalline and quasi-monocrystalline Si ➢ Doping ➢ Crystal defects, impurities and segregation ➢ Production capacity and industrial market Sawing of silicon substrates Energy balance and carbon footprint of the production of Si wafers
	Module4	*Title:* The silicon photovoltaic cell
		Description: p-n junction and operating principle of the PV cell Equivalent electrical diagram and key parameters of the PV cell Physical and technological losses Quantum efficiency and spectral response History and technological evolution of the silicon PV cell Industrial and laboratory conversion efficiencies

			Architecture of a standard PERC PV cell and overview of the industrial manufacturing process
	Module5	*Title:*	Industrial manufacturing process for standard PV cells (PERC)
		Description:	Chemical cleaning and texturization ➢ Optical constants, reflectivity and minimization of optical losses ➢ Chemical and plasma etchings Diffusion and formation of the p-n junction ➢ Semiconductor doping and p-n junction ➢ Emitter diffusion: theory, selective diffusion, gettering and industrial equipment Thin films deposition: anti-reflective and passivation layers ➢ Anti-reflective coating and minimization of optical losses; optical characterization ➢ Recombination mechanisms, passivation of surface and volume defects ➢ Thin film deposition processes (PECVD, PVD, ALD, oxidation, etc.) and industrial equipment ➢ Thin film characterization: theory of measurements and characterization equipment Metallization of the contacts on the front and rear faces ➢ Laser opening, screen printing and rapid annealing furnace ➢ Metal-Silicon contacts, Back Surface Field, hydrogenation and gettering The PERC+ bifacial cell ➢ Bifaciality coefficient and bifacial gain ➢ Modification of the industrial process Characterization of PV cells: principle and laboratory and industrial equipment
	Module6	*Title:*	Evolution of silicon PV technology: innovative architectures of silicon PV cells
		Description:	Silicon quality and wafer size From p-type silicon to n-type silicon: architectures and industrial fabrication processes for PERT cells, high temperature passivating contacts (TOPCon), heterojunctions (HJT), and interdigitated back contacts (IBC)

			Metallization of cells: bifaciality and selective passivating contacts Industrial issues and research routes for the development of large-scale PV
	Module 7	*Title:*	Future of PV technology: perovskite / silicon tandem cells
		Description:	The exceptional growth of perovskite solar cells Development of perovskite / silicon Tandem cells for an efficiency greater than 30%
	Module 8	*Title:* CEA-INES research laboratories tour	
		Description:	Silicon crystallization Fabrication and characterization of PV cells Fabrication, characterization and accelerated ageing of PV modules Outdoor research platform of PV systems
	Module 9	*Title:* INES-PFE pedagogical platform tour	
		Description:	Outdoor pedagogical platform of PV systems showing the different practical applications of PV Indoor pedagogical platform of PV systems (components, wiring, installation, safety…)
MATERIALS	☐ *videos* ☒ *Documents (pdf, doc)* ☒ *Presentations (ppt)* ☐ *Self-assessment activities* ☐ *Auto-assessment activities* ☐ *Tutored activities* ☒ *Lectures (On-site)* ☐ *Lectures (On-line)* ☒ *Activities based on laboratory practices (Research laboratories tours and pedagogical platform)* ☐ *Activities based on software simulations* ☐ *Activities based on peer activities* ☐ *Infographics* ☐ *Podcasts*		
EXTERNAL RESOURCES	☒ *Links to webs* ☐ *Videos* ☐ *Tutorials* ☒ *Books/chapters* ☒ *Journal articles/conference papers* ☐ *Related/complementary modules/courses (links to other ECOVEM courses)*		

	☒ Other (*Add as many lines as needed*) exhibition of different generations of solar PV cells and modules + research samples
ASSESSMENT AND EVALUATION (Each module should have its own evaluation as well as the whole course)	**Percentage of completion** ☐ *Assessment based on completion materials (videos, quizzes, etc.)* **Auto-assessment tasks** ☒ *Fixed quizzes* ☐ *Adaptative quizzes* ☐ *Drag and drop activities* ☐ *Video-quizzes* ☐ *Virtual simulators* **Peer assessment tasks** ☐ *Assessment based on peer activities* **Self-assessment tasks** ☐ *Essay based on topics and providing a document as solution* ☐ *Laboratory practices - laboratory work* ☐ *Assessment based on software simulation activities* **Teacher assessment tasks** ☒ *On-site examination* ☐ *On-line examination* ☐ L*aboratory practices - laboratory work* ☐ *Assessment based on software simulation activities*
HOME IMAGE OF THE COURSE (jpg or png)	
INNOVATIVE LEARNING METHODOLOGIES (We included in the Project Proposal the Performance-centered approach and gender and inclusive diversity)	☐ *Performance-centered approach and Electronic Performance Support Systems* ☒ *Innovation in instructional design* ☐ *Project-Based Learning* ☐ *Activity Based Learning* ☐ *Simulation Based Learning* ☐ *Remote and Virtual Laboratories* ☐ *Blended Learning* ☐ *Microlearning* ☐ *Open educational resources (OER)*

INTERNAL COMMENTS :	**This course is modular and adjustable in terms of duration and technical level (EQF 6 to 8). The modules of courses 6.1 and 6.3 can be combined with this course according to trainees' skills and expectations**