ENEA Activities in Solar Energy*

AGENZIA NAZIONALE
PER LE NUOVE TECNOLOGIE, L'ENERGIA
E LO SVILUPPO ECONOMICO SOSTENIBILE

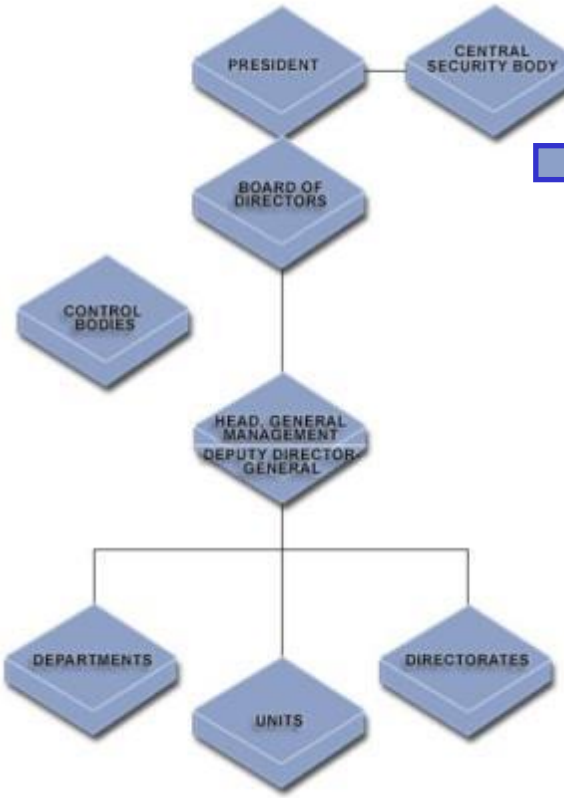
Francesco Roca*

ENEA - Energy Technologies Department,

CR Portici, Naples- Italy

ENEA- Italian National Agency for the new Technologies, Energy and Sustainable Economic development

Organizational Structure (Dec 2015)



3 Technical Departments (~1640 people)

7 Units (~310 people)

White certificates. Radiation Protection Istitute, Antartica project, Energy Saving Agency etc

5 Directorates (~610 people)

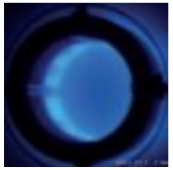
Central administration, planning and control & logistic,

9 Research Centers

5 local laboratories

Brussels Liason Office and Territorial offices

Research and Development



Fusion & Nuclear safety

- Fusion
- Fission (new gen)
- Radiation protection
- Nuclear safety & security
- Ionizing/non ionizing radiation applications

Energy technologies

- CSP and thermal solar energy, including thermal energy storage
- Photovoltaics and smart grids
- Energy efficiency technologies, including efficient conversion and use of energy, electric energy storage
- Bioenergy, biorefinery and greenchemostry
- Smart energy & smart cities
- Sustainable mobility
- Fuel cells and hydrogen
- Sustainable use of fossil fuels
- ICT

Sustainability of territorial systems

- Resource efficiency
- Environmental technologies
- Climate change: modeling, adaptation and mitigation
- Prevention and Recovery
- Seismic and natural hazards assessment and prevention
- Bio and nanotechs
- Agrifood

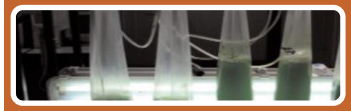
DTE-Energy Technologies Department

Photovoltaics and Smart Network

- New generation PV systems and concentrated photovoltaic (CPV)
- New PV materials: Thin film, high-efficiency PV cells, organic photovoltaics
- Smart Grids and use services of RES in electricity distribution grids

Thermal and Thermodynamic Solar Division

- Research Facility with linear parabolic collectors and molten salts heat pipes (ENEA patented technology). R&D activities on innovative thermal storage system.
- Optimization of solar collectors, development of components and systems for solar coling



Bioenergy, Biorefinery and Green Chemistry

- Production of syngas from agricultural waste, from biomass, as well as chemicals
- Production of bio-fuels from micro-algae

Efficient Production, Conversion and Use of Energy

- Electrochemical systems for the conversion and storage of hydrogen energy, supercapacitors
- Co-generation systems, fuel cells, new materials, high-efficiency lithium batteries
- Sustainable use of fossil fuels (CCS)
- Sustainable mobility

Smart Energy

- Smart public lighting
- Smart cities
- Smart Building Energy Management Systems (BEMS) and demand-response systems

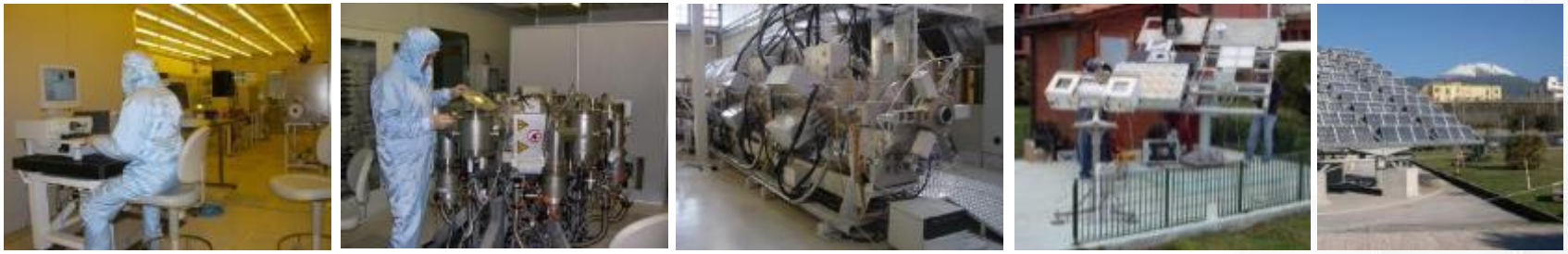
ICT (service)

- High Performance Computation
- ICT for running project

Solar Energy in ENEA
Human and lab resources

DIVISIONS	Laboratories and assigned human resources to Solar Energy	
SOLAR THERMODINAMIC & THERMAL DTE-STT	**65** permanent staff **2** unit-laboratories	▪ ITES- Development of components and Solar Pants Lab ▪ SCIS- Engineering of Solar Technologies Laboratory
PHOTOVOLATICS and SMART NETWORK DTE-FSN	**76** permanent staff **4** unit-laboratories	▪ DIN-Innovative Device Laboratory ▪ TEF-Photovoltaics Technologies Laboratory ▪ FOSG-Photovoltaic Systems and smart network lab.
TECHNOLOGIES AND MATERIAL FOR THE SUSTAINIBILITY SSPT*- PROMAS	**8** permanent staff **1** unit-laboratories	▪ NANO-Nano-materials and Organic devices lab * *SSPT- Territorial and Production Systems Sustainability Department

ENEA Casaccia & Trisaia



ENEA Portici

SOLAR PHOTOVOLTAICS
IN ENEA

Enea PV Activities:"value chain"

Materials

- Thin Silicon film
- Thin Silicon on polimeric substrates
- Epi-wafer approach
- Thin Polycrystalline (kesterites)
- Nanomaterials & Graphene
- Trasparent Conductive Oxide
- Advanced dielectric coating

Devices

- Tandem/micromorph Solar Cells
- aSi/cSi Solar Cells
- High Efficiency cSi Solar Cell (PVC)
- OPV & DSSC Solar cells
- Indoor/outdoor characterization of Solar cells

Sistems

- PV Modules Indoor/outdoor Qualification
- Definition of standards
- Energy prediction
- Smart PV modules
- Reliability Analysis on BOS Components
- Solar Tracking
- PV module Recycling

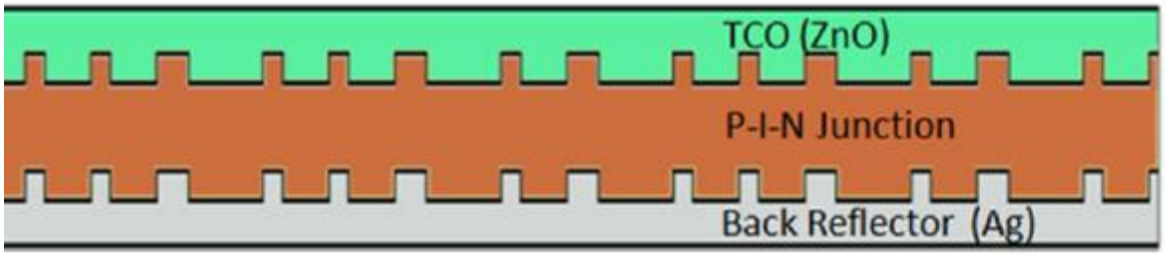
Applications

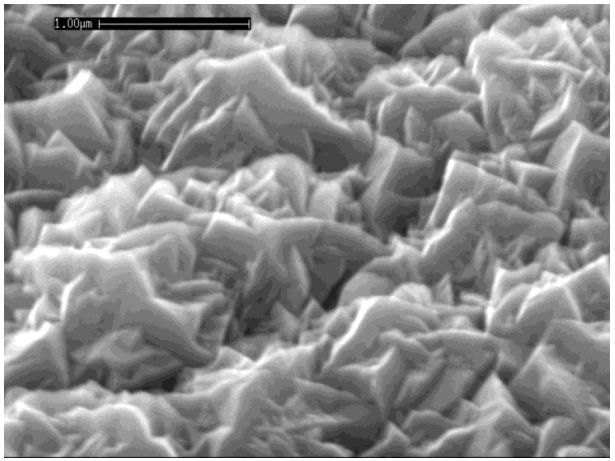
- Distributed generation
- Large plants
- Hybride Solar/Thermal application
- Smart grid
- BIPV & Ecobuildings design
- PV demo sites
- Market&Incentives

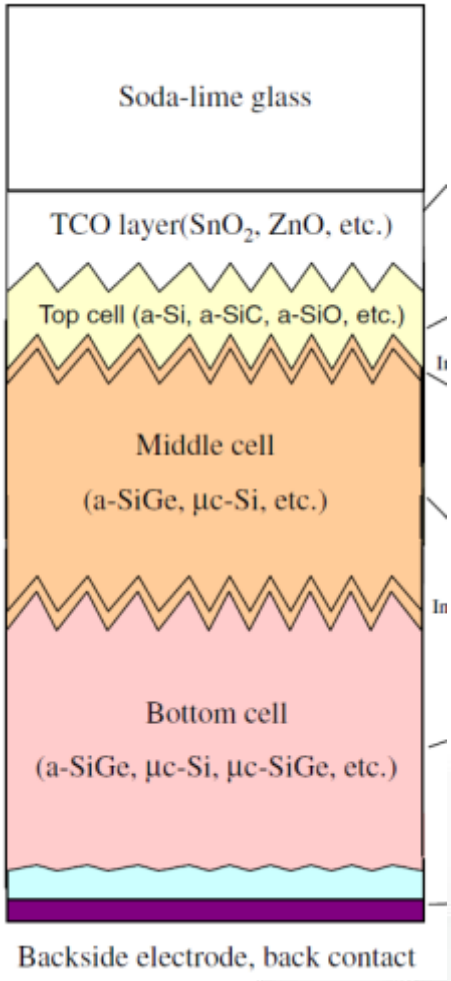
Thin film silicon based solar cells

Innovative absorber and doped materials for multijunction silicon solar cells

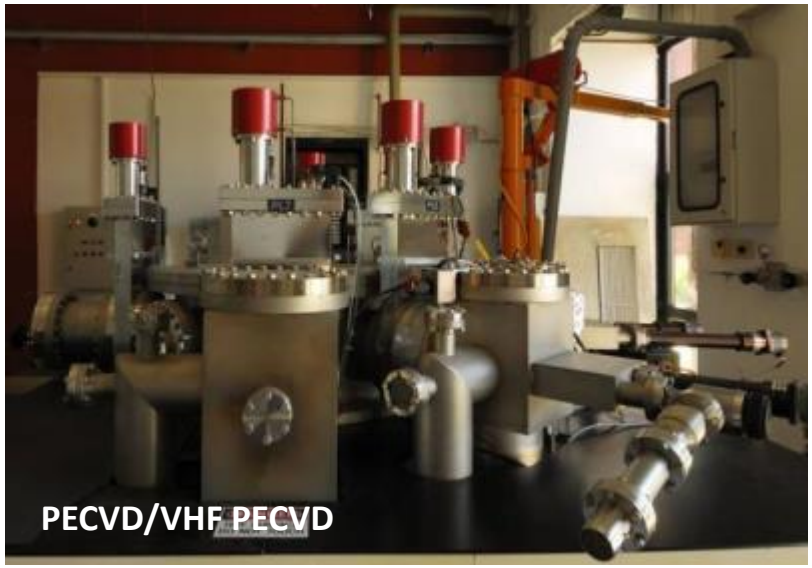
Textured substrates and new architectures for an optical improvement of the thin film Si device performance

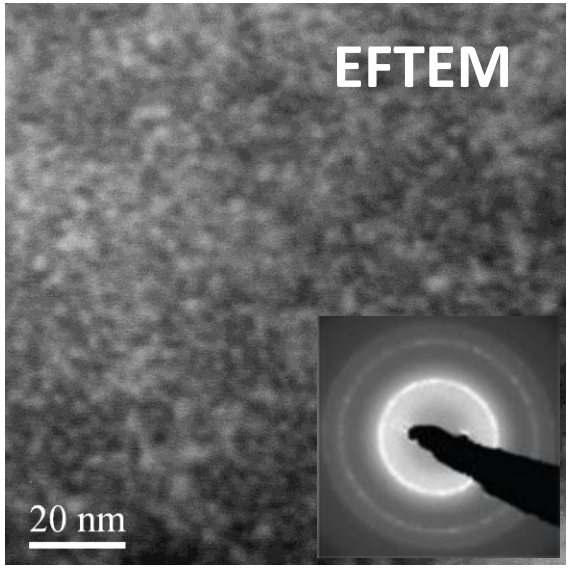






Thin film silicon based solar cells:
PECVD grown n-SiOx films

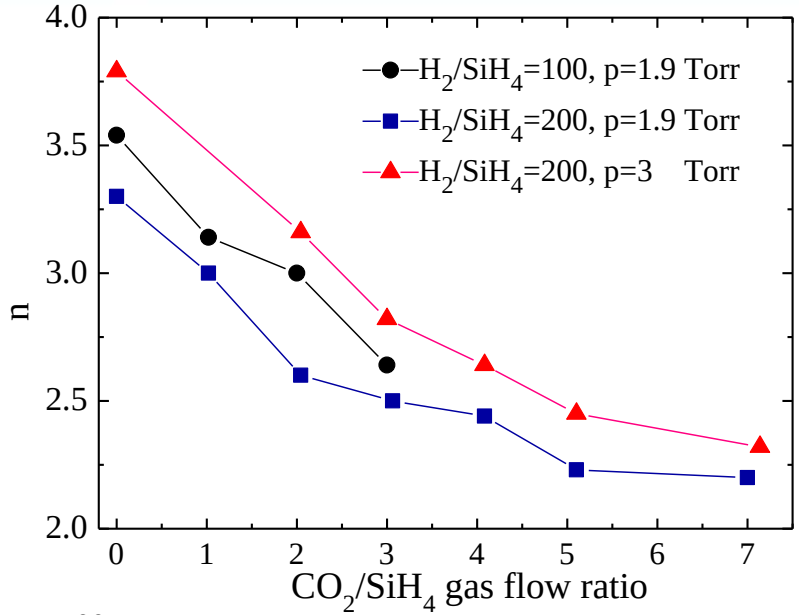


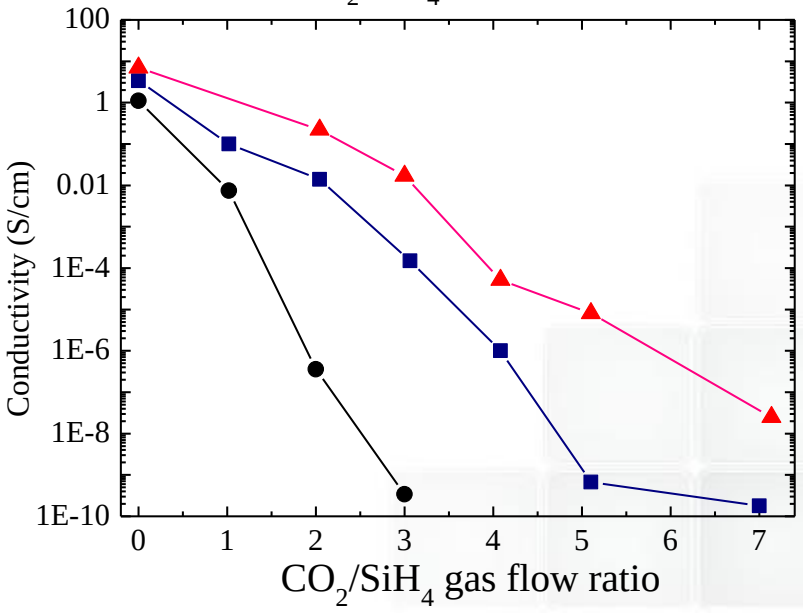


CO_2/SiH_4 = 3,
1.9 Torr

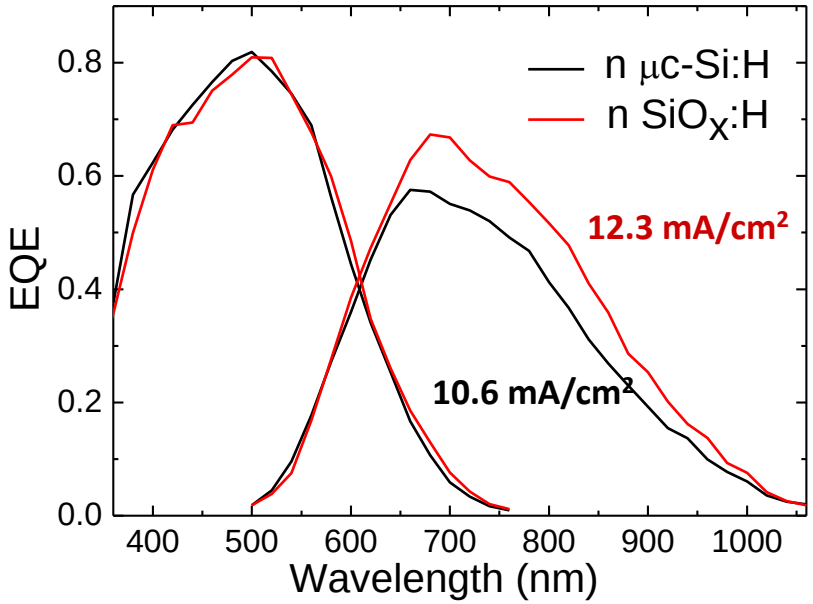
light = Si rich phase
dark = O rich phase

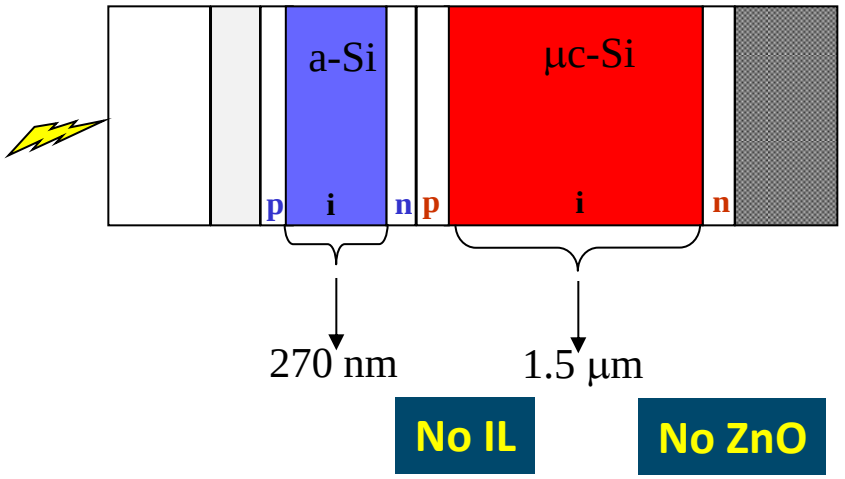
JEOL 2010F 200KeV
EFTEM @ CNR IMM
Catania

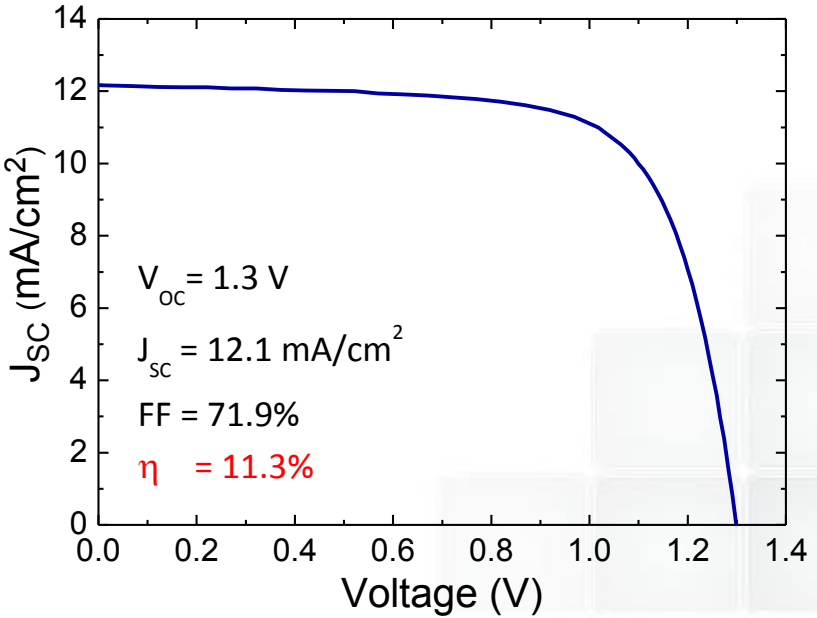




Thin film silicon based solar cells: n-SiOx:H in micromorph devices





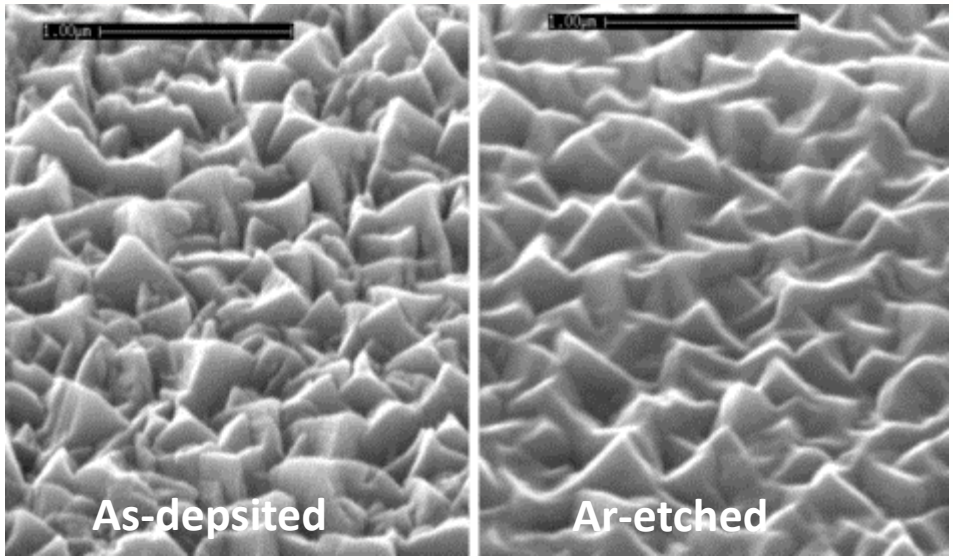


P. Delli Veneri, L.V. Mercaldo, I. Usatii Appl. Phys. Lett. 97, 023512 (2010);

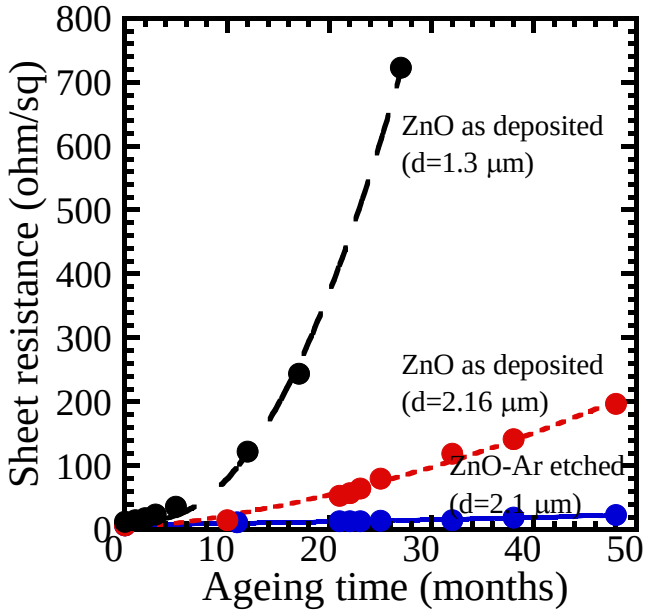
P. Delli Veneri, L.V. Mercaldo, I. Usatii, Prog. Photovolt: Res. Appl. 2013; 21:148–155

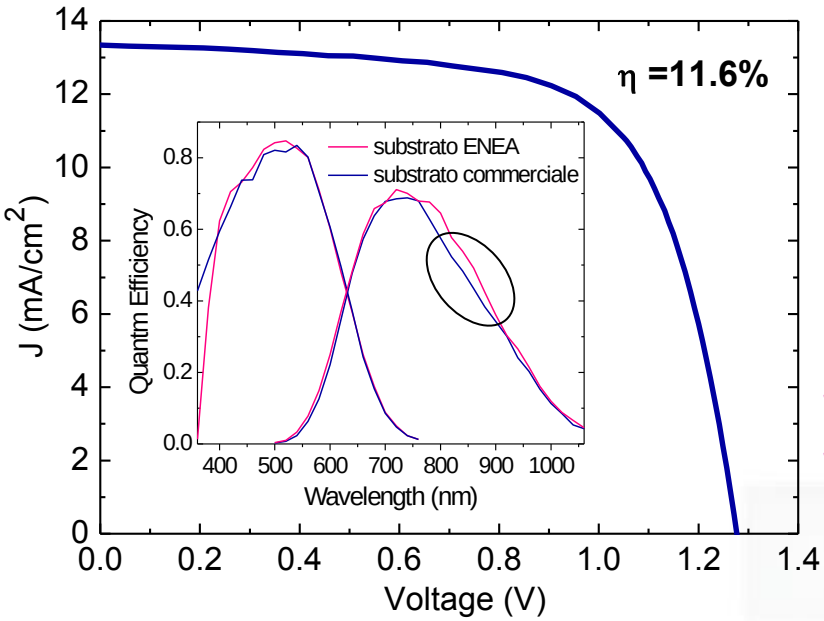
L. V. Mercaldo, P. Delli Veneri, I. Usatii, E. M. Esposito, G. Nicotra, Solar Energy Materials & Solar Cells 119 (2013) 67–72

Ligth trapping strategies for silicon based solar cells: Development of MOCVD grown ZnO



ENEA Patent RM2008A000405

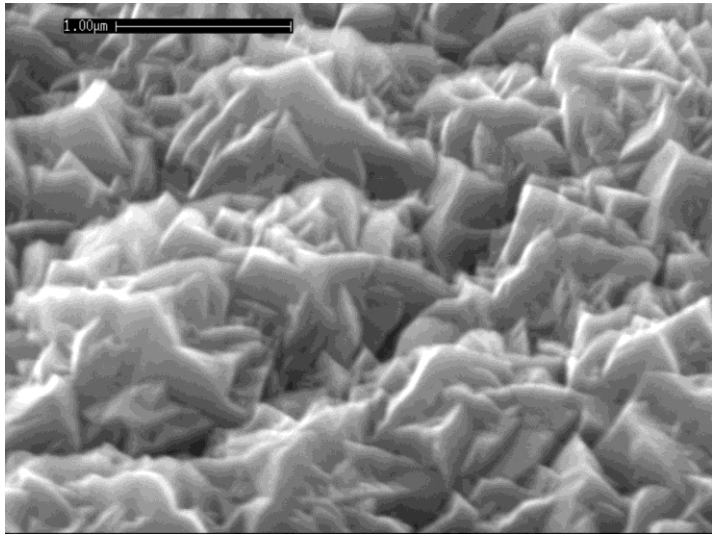


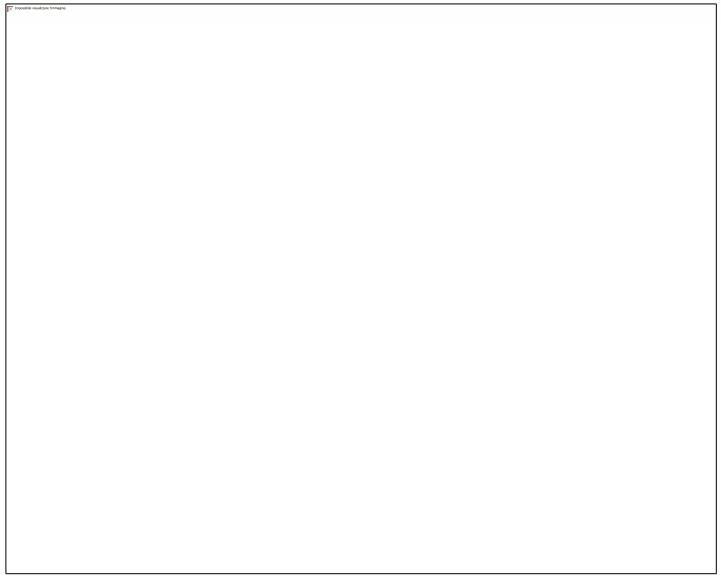


Better infrared spectral response with LPCVD ZnO with respect to commercial TCO

Light trapping strategies for silicon based solar cells

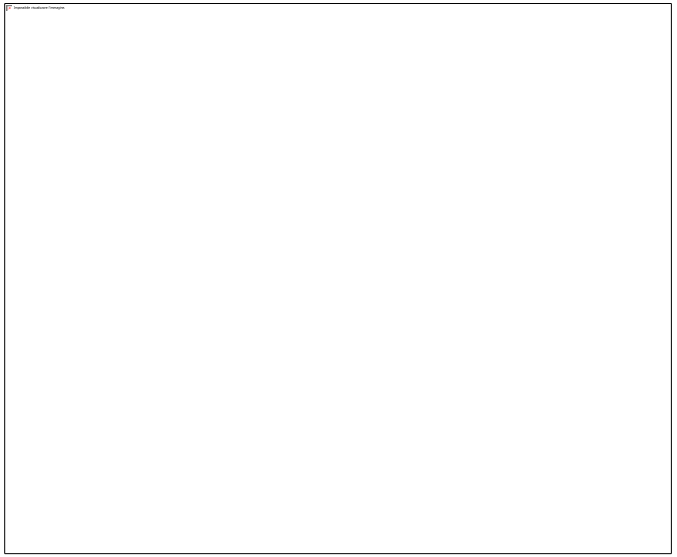
Double textured ZnO





M. L. Addonizio and A. Antonaia, J. Phys. Chem. C 2013, 117, 24268−24276
M.L. Addonizio, A. Spadoni, A. Antonaia, Applied Surface Science 287 (2013) 311– 317

Development of textured glass



Aluminium Induced Texture

- ✓ Metal deposition
- ✓ Thermal annealing near 600°C
- ✓ Chemical etching

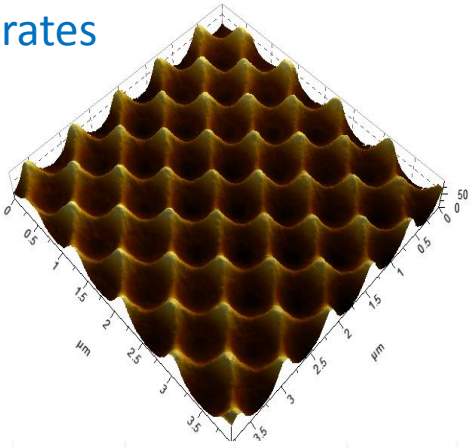
WET etching

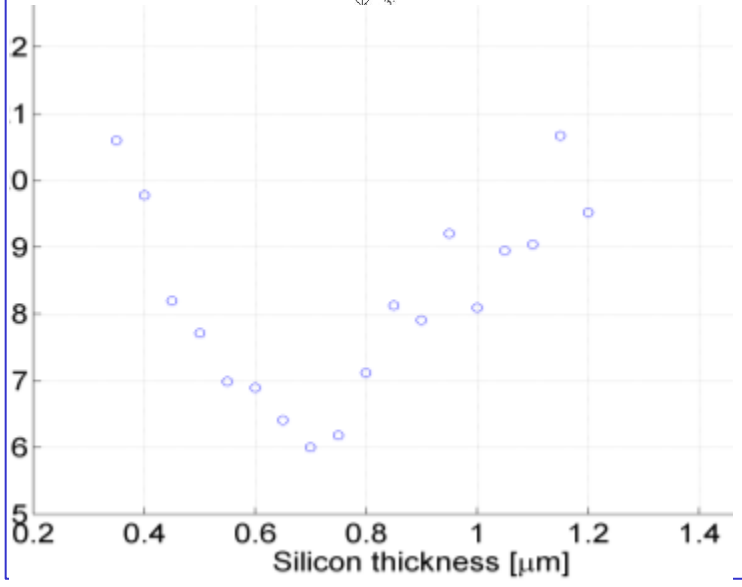
In cooperation with University «Federico II» of Naples

Light trapping strategies for silicon based solar cells: **periodic and quasiperiodic structures**

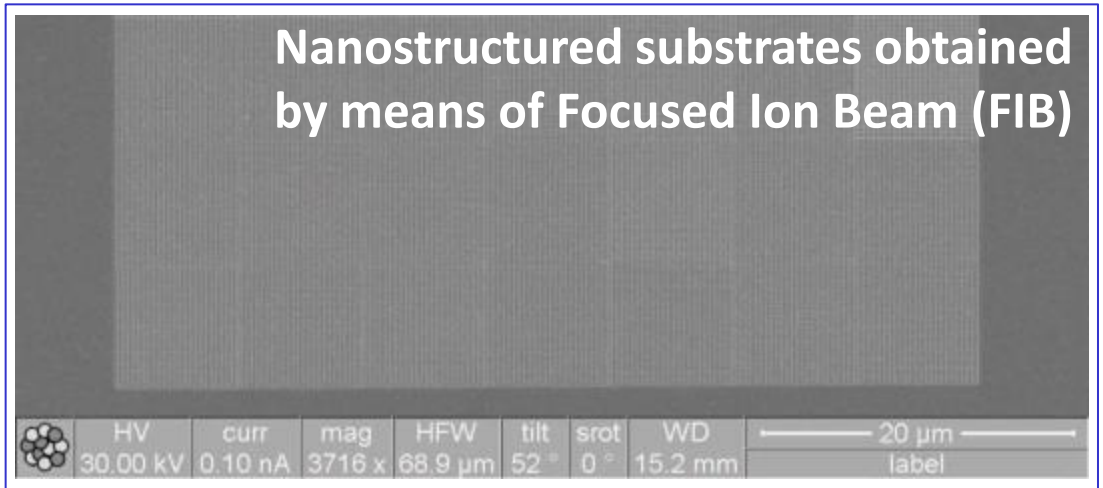
In cooperation with University of Sannio

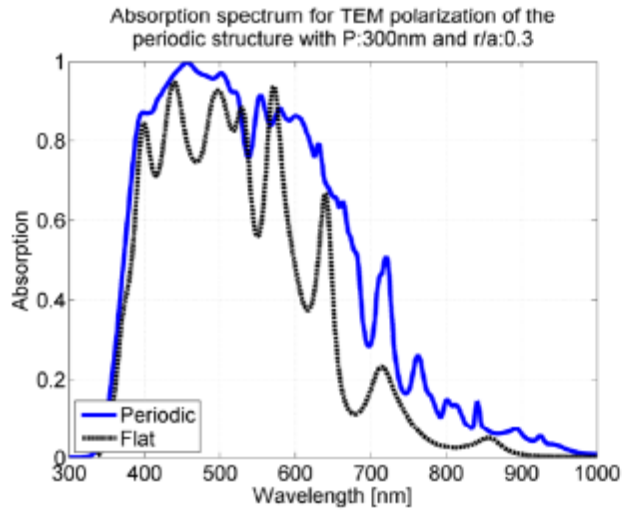
Relationship between the cell thickness and the period of textured substrates





Nanostructured substrates obtained by means of Focused Ion Beam (FIB)



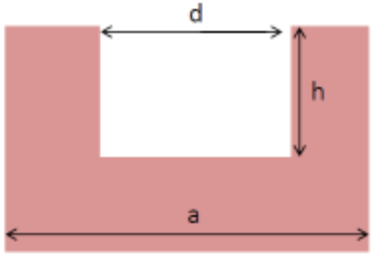


Master parameters

a = 300 nm

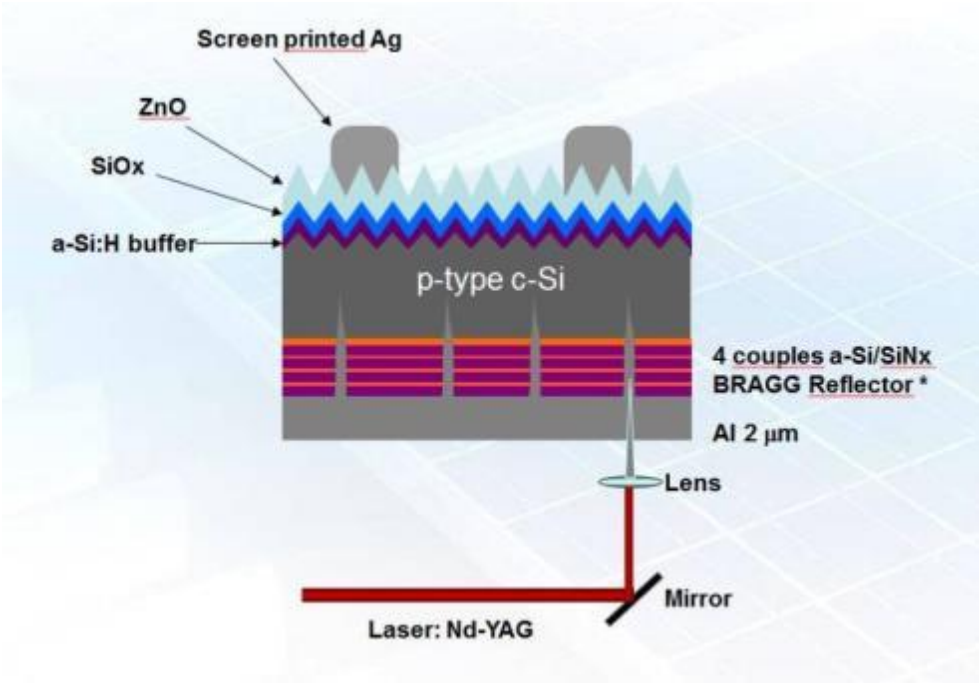
h = 300 nm

d = 180 nm



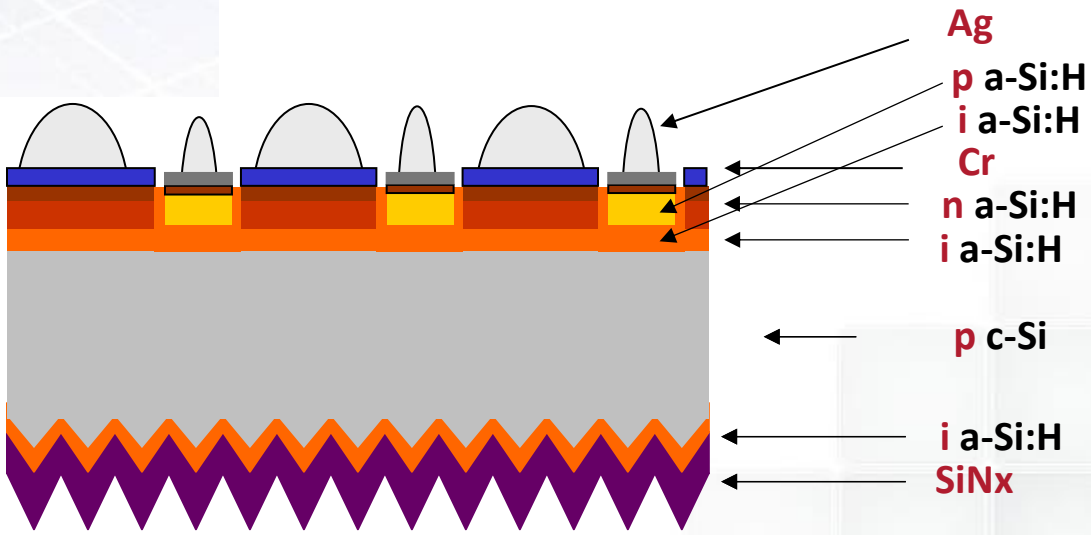
A. Micco, A. Ricciardi, M. Pisco,V. La Ferrara, L. V. Mercaldo, P. Delli Veneri, A. Cutolo, and A. Cusano, Journal of Applied Physics 114, 063103 (2013)

Heterojunction a-Si/c-Si solar cells

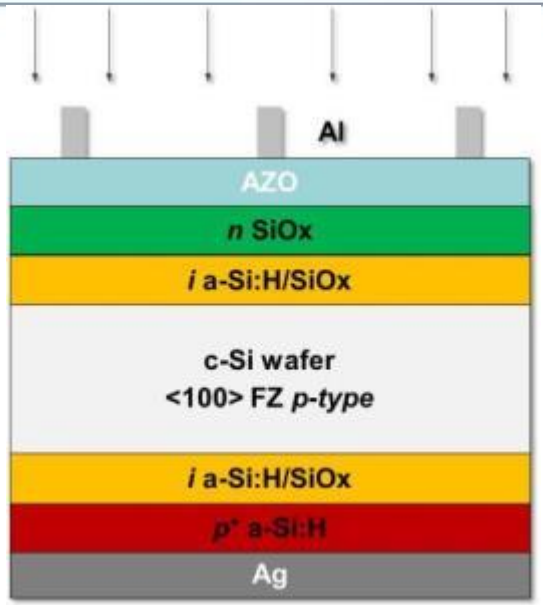


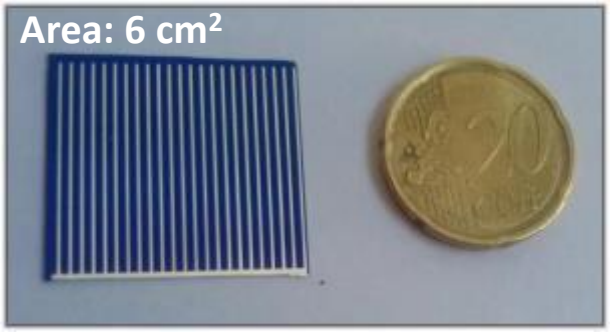
Solar cell architectures

BEHIND CELL Back
Enhanced
Heterostructure with
INterDigitated contact cell



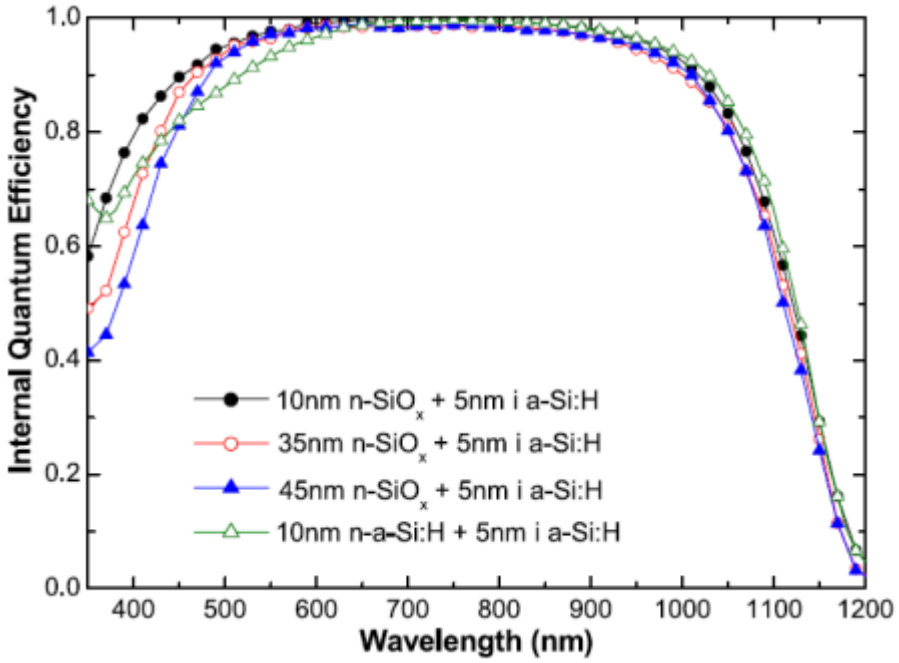
Heterojunction a-Si/c-Si solar cells





Current status:

V_{OC}= 644 mV
J_{SC}=37 mA/cm² on active area
FF=73%
η= 17.4%



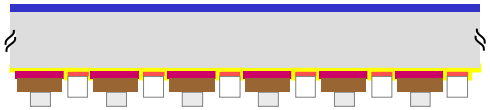
M. Izzi , M. Tucci, L. Serenelli, P. Mangiapane, M. Della Noce, I. Usatii, E. Esposito, L.V. Mercaldo, P. Delli Veneri, Appl Phys A, 2014, Volume 115, Issue 2, 705.

Heterojunction a-Si/c-Si solar cells: BEHIND CELL

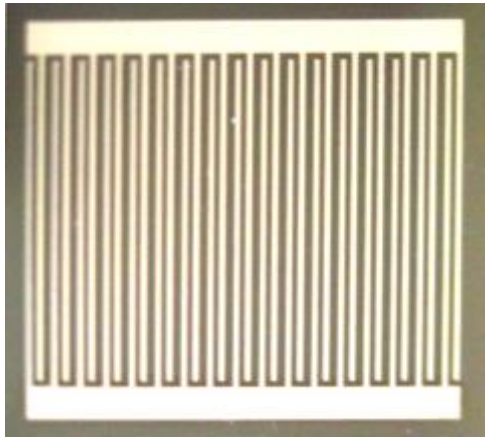
Back Enhanced Heterostructure with INterDigitated contact cell

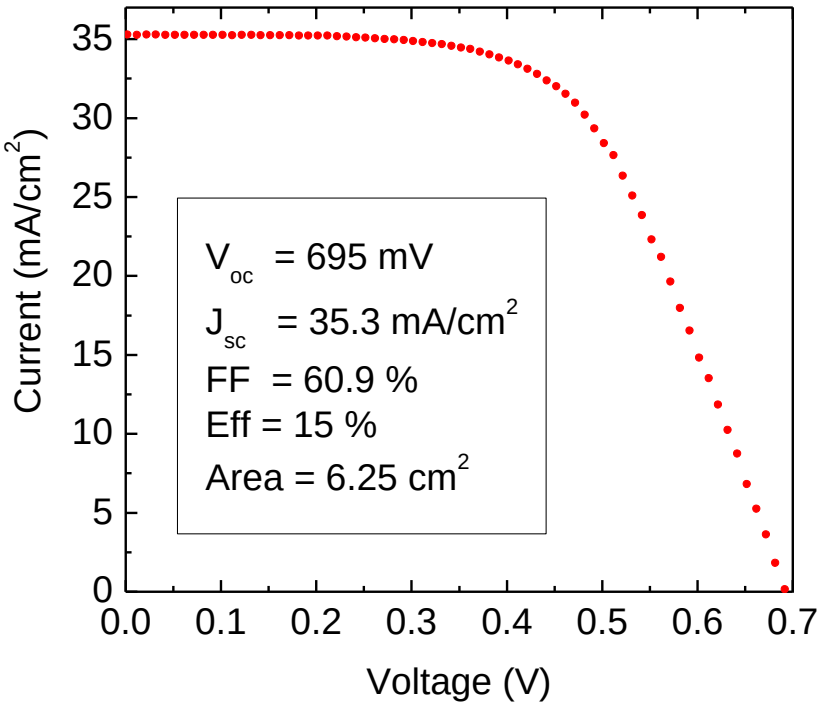
Front side

Cross section



Rear side contacts





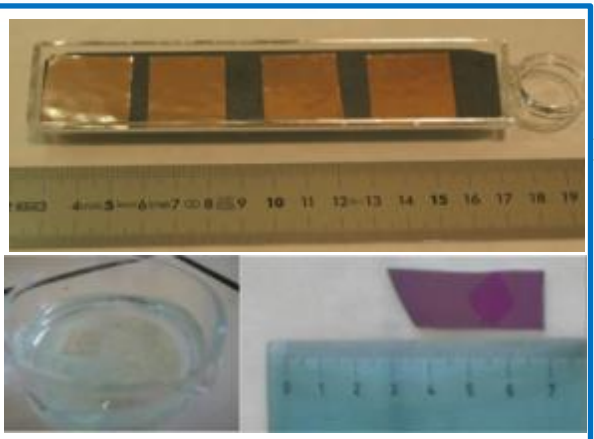
This structure allows to enhance cell efficiency up to 24%

ENEA patent # BO2007A000717

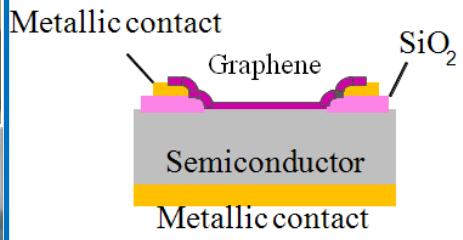
M. Tucci, L. Serenelli, E. Salza,, S. De Iuliis, L.J. Geerligs , D. Caputo, M. Ceccarelli, G. de Cesare; Journal of non-cryst. solids 354 (2008) 2386.

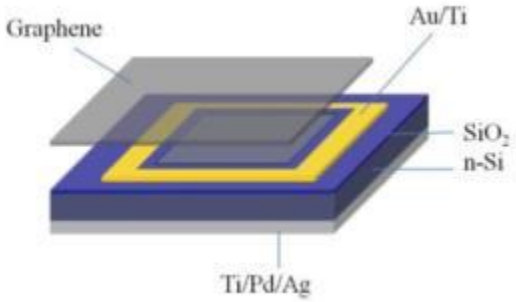
Graphene/n-Si heterojunction solar cells

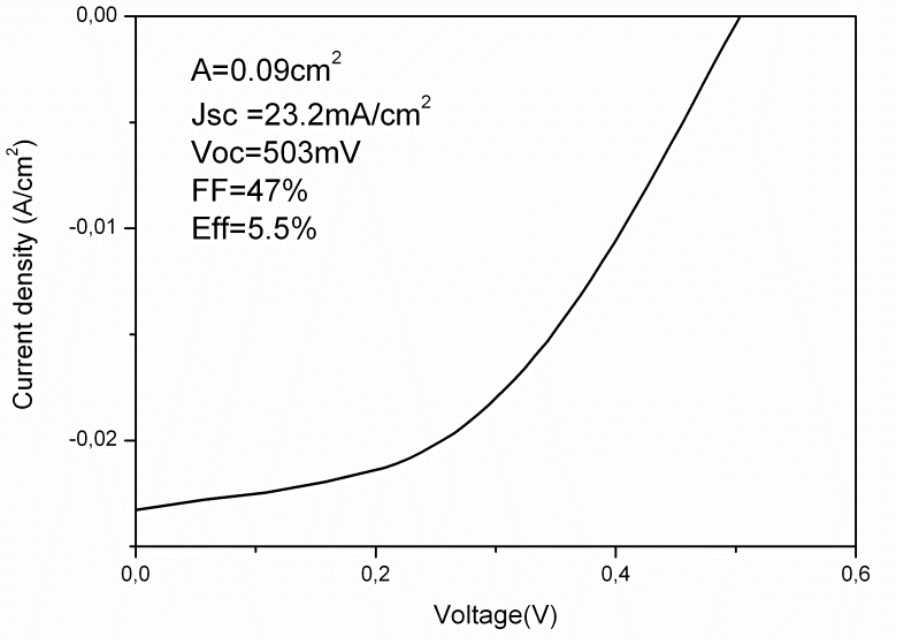
Graphene films are grown on copper foil substrates by a non toxic and low-cost ethanol based CVD near1000°C

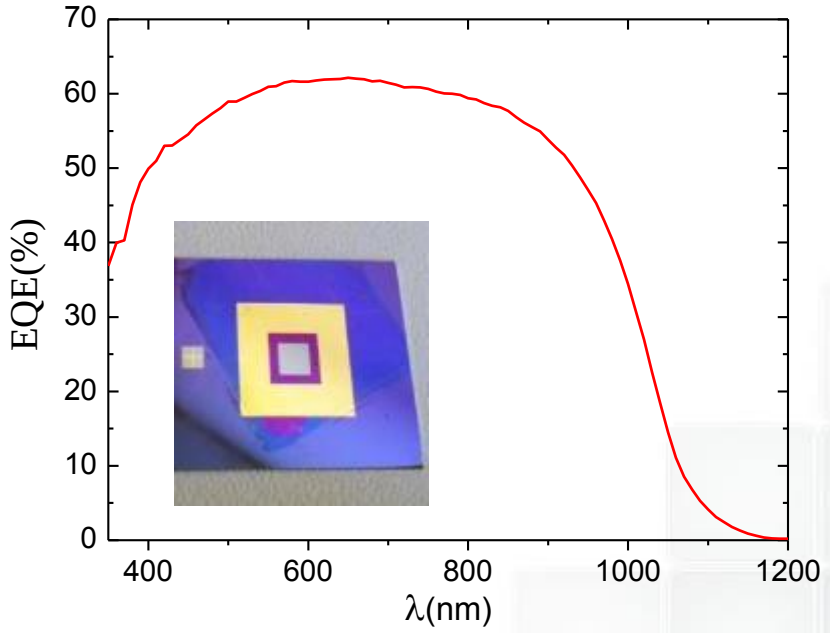


ENEA DTE-FSN-DIN Lab.







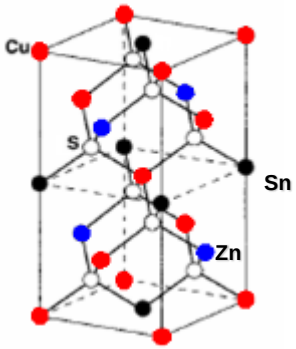


L. Lancellotti, E. Bobeico, A. Capasso M. Della Noce, T. Dikonimos, N. Lisi, P. Delli Veneri, submitted to IEEE xplore

Thin film PV : Cu_2ZnSnS_4

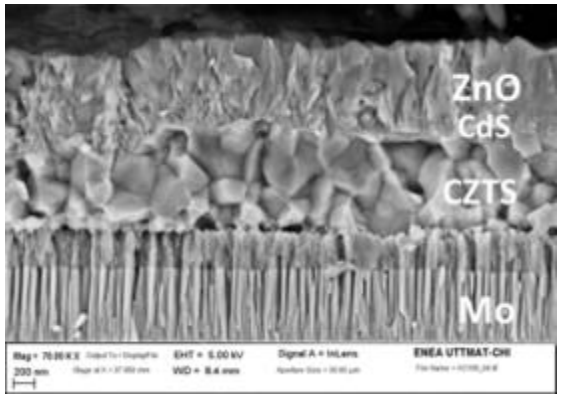
CZTS is an interesting PV material for two applications:

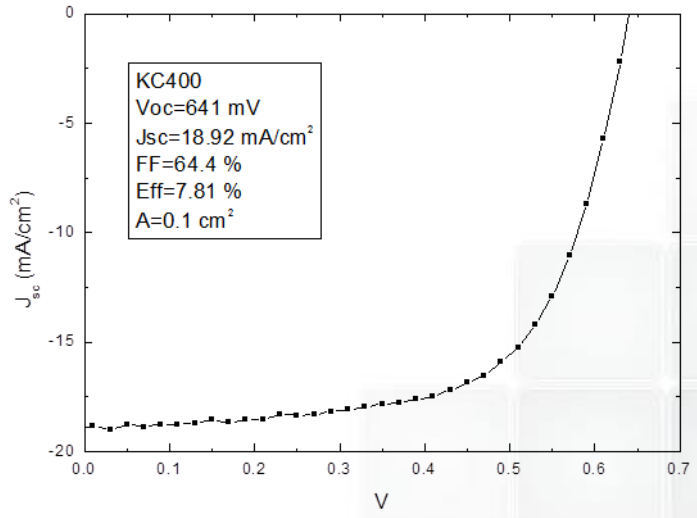
- Replacement of **CIGS** with an **indium free materials**.
- Development of a thin film PV device with a gap suitable for tandem application (Eg of CZTS can reach 1.65 eV with a good order level of the Cu and Zn cations)



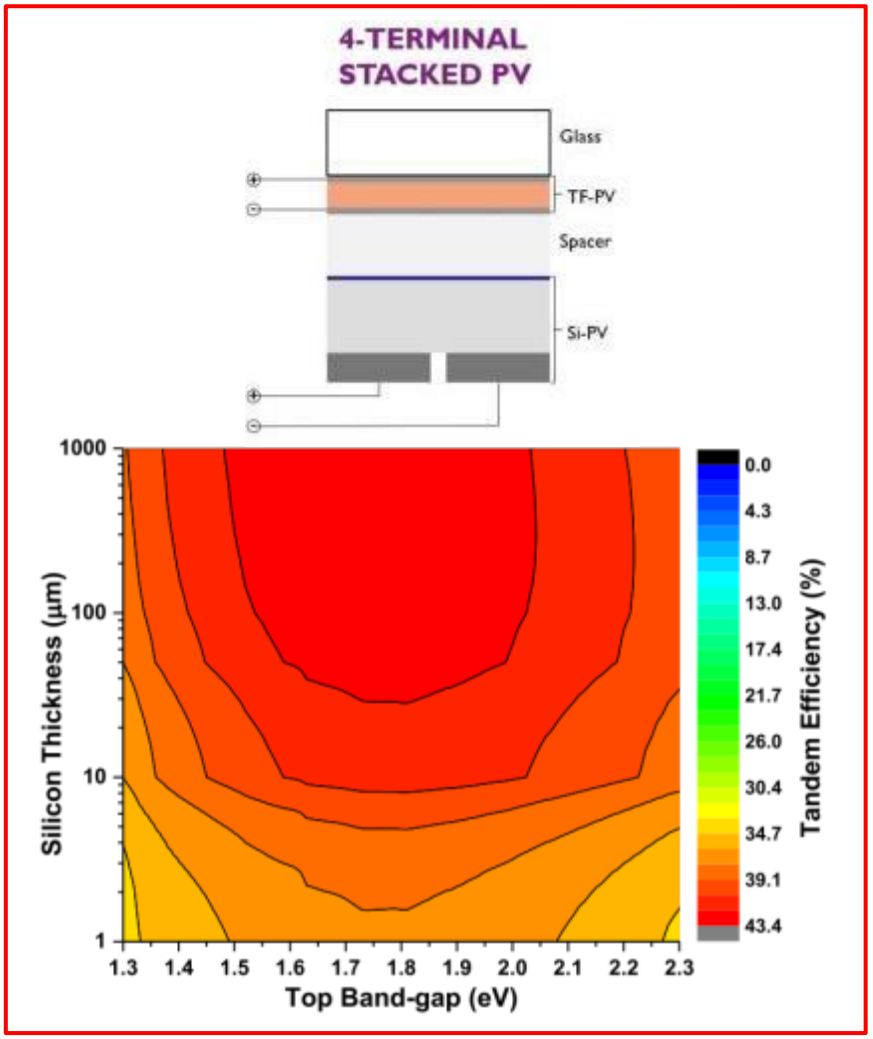
Cu_2ZnSnS_4
"CZTS"

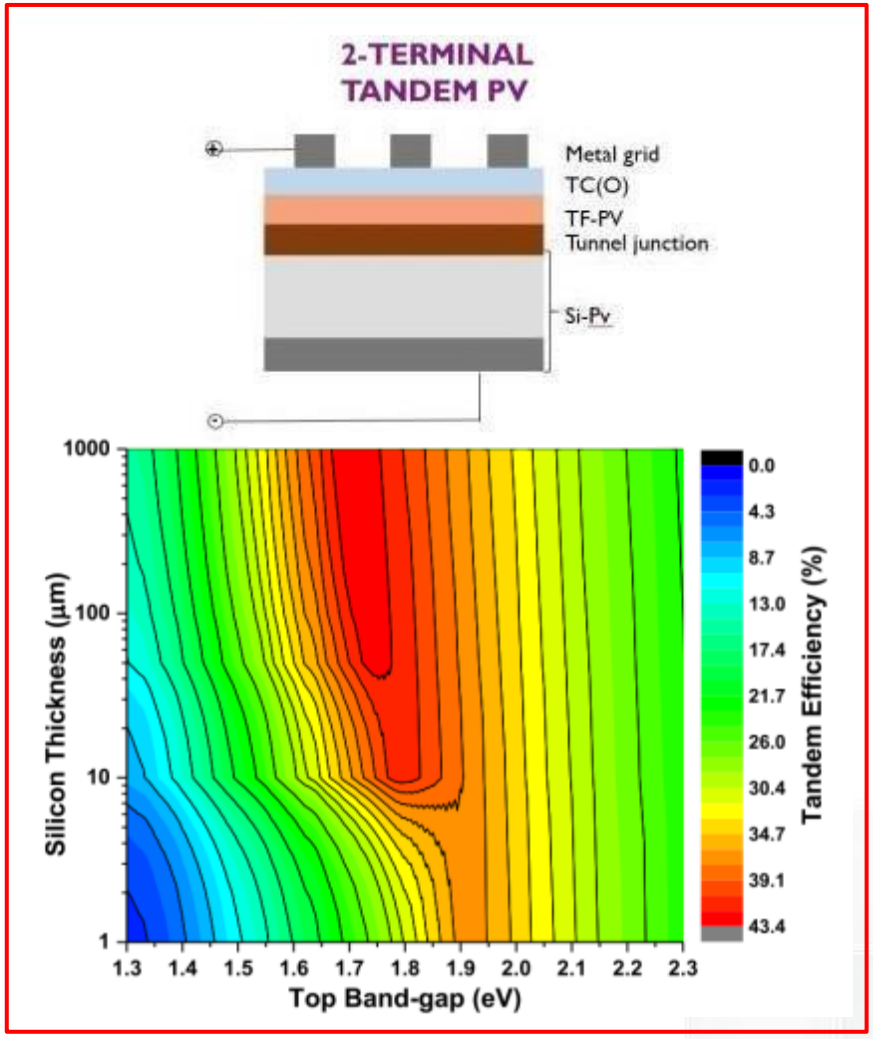
ENEA is developing a complete process to fabricate CZTS devices starting from co-sputtered precursors.





Final goal: tandem cell (thin film + c-Si)

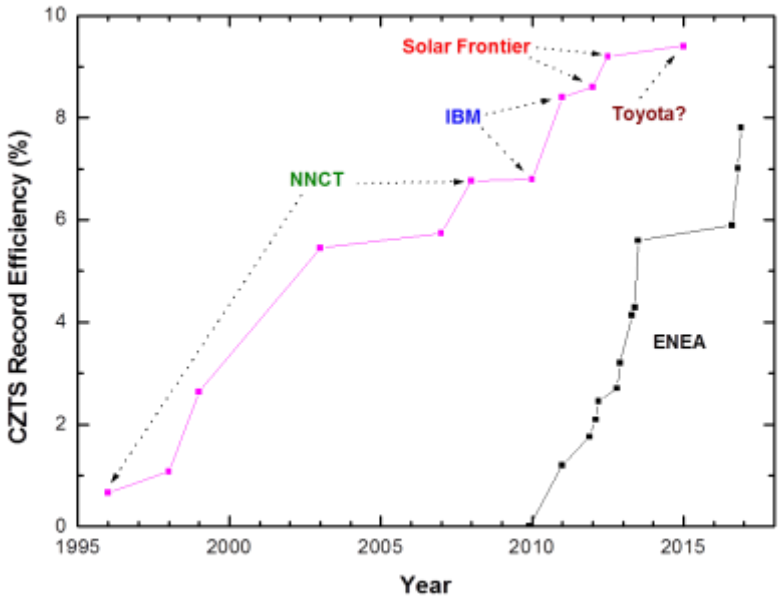




I. Almansouri, et al.," Supercharging Silicon Solar Cell Performance by Means of Multijunction Concept", IEEE J. Photov., ***5****, 968 (2015)*

ENEA ranking in CZTS research

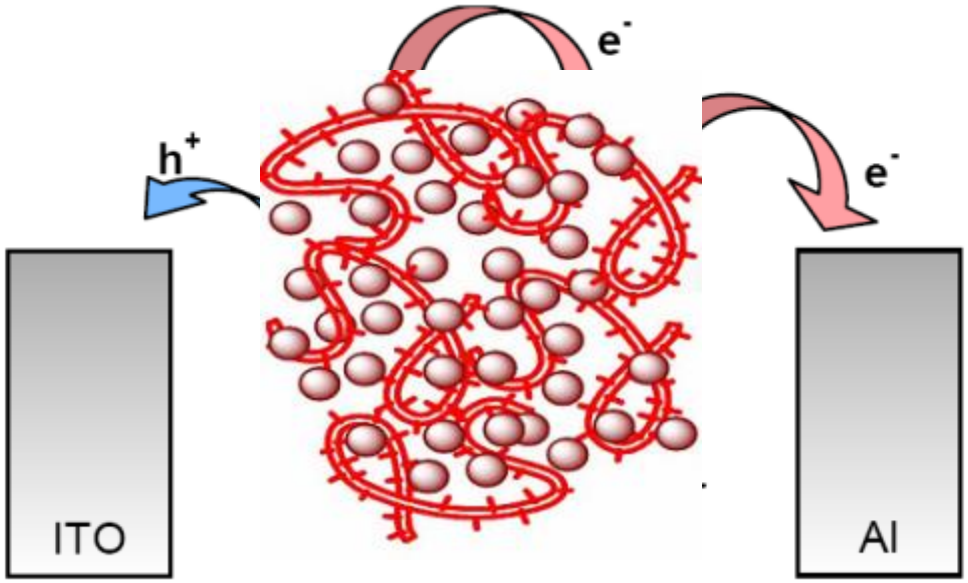
	Growth techinque	buffer	Eff %	Voc mV	Jsc mA/cm²	FF	Area cm²
Solar Frontier (2011)	Stack evaporation + sulfurization	In_2S_3/CdS	9.2	708	21.6	60.1	14.9
UNSW (2016)	Co-sputt. Cu, ZnS, SnS + sulfurization in S	(Zn,Cd)S	9.2	748	19.5	63.2	0.4
Toyota (2015)	Co-evaporation Cu, Zn, Sn, S + hot plate 570° C in S_2/N_2	CdS	8.8	710	17.5	71.0	0.24
Shenzhen Inst. Ad. Tech. (2016)	Co-sputt. Cu-SnS_2-ZnS + Sulfurization in H_2S/N_2 at 300 Torr	CdS	8.6	625	21.1	65.1	0.5
IBM (2011)	Co-evaporation Cu, Zn, Sn, S + hot plate 570° C in S_2/N_2	CdS	8.4	661	19.5	65.8	n. a.
Osaka Univ. (2015)	Elettrodep . stack Cu-Sn-Zn + Solf. In sealed ampoule with S	CdS	8.1	705	18.0	63.2	0.05
ENEA (2016)	Co-sputt. Cu, ZnS, SnS + sulfurization in S	CdS	7.8	641	18.9	64.4	0.1
DGIST (Korea) (2015)	Sputtering stack Mo/ZnS/SnS/Cu + Sulfurization in S	CdS	7.5	632	19.2	61.6	n.a.
Uppsala (2015)	Reactive co-sputt. Cu, Zn, Sn, S + sulfurization in Ar+ S	(Zn,Sn)O	7.4	682	17.9	60.2	0.1
Katagiri group (2008)	Co-sputt. Cu, ZnS, SnS + sulfurization in H_2S/N_2	CdS	6.8	610	17.9	62.0	0.15



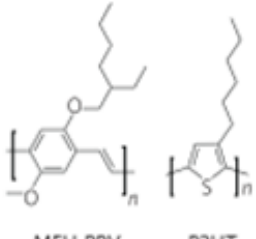
Use of a buffer layer better than usual CdS is important to obtain larger values of Voc. This topic will be the next step in the ENEA strategy.

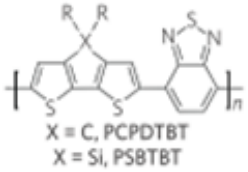
Polymer solar cells - ENEA-SSPT-NANO

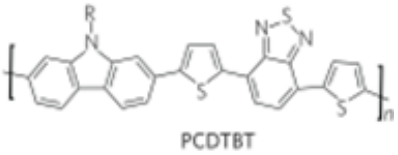
Laboratory for Nanomaterials and Devices

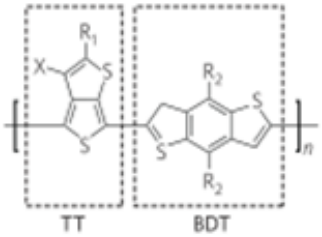


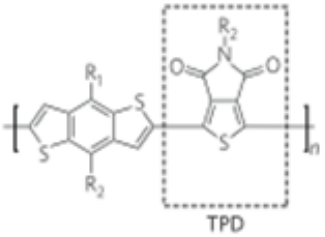
Donors



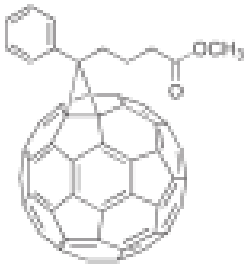


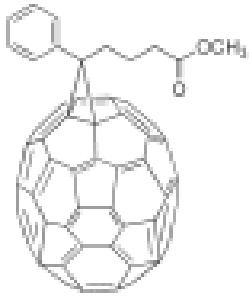






Acceptors





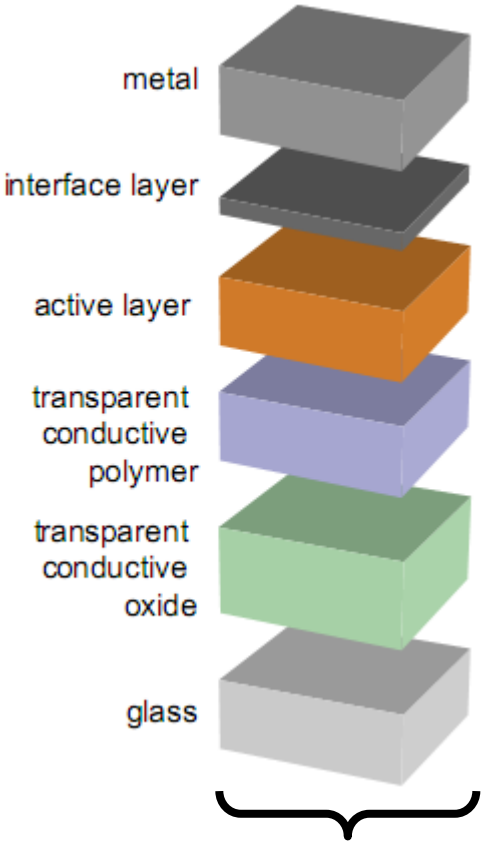
P. Morvillo, F. Parenti, R. Diana, C. Fontanesi, A. Mucci, F. Tassinari, L. Schenetti, *Solar Energy Materials and Solar Cells*, 104, 45-52, 2012

P. Morvillo, R. Diana, C. Fontanesi, R. Ricciardi, M. Lanzi, A. Mucci, F. Tassinari, L. Schenetti, C. Minarini, F. Parenti, *Polymer Chemistry*, 5, 2391-2400, 2014

A. Bruno, F. Villani, I. A. Grimaldi, F. Loffredo, P. Morvillo, R. Diana, S. Haque, C. Minarini, *Thin Solid Films*, 560, 14-19, 2014.

Research activities on OPV

ENEA-SPTT-NANO



Ca/Al (standard)or Ag (inverted)

Blend morphology optimization,
Modeling and testing of new and commercial materials

PEDOT:PSS or MoOx (standard) or ZnO (inverted)

ITO replacement with HC-PEDOT:PSS

PSC realization on flexible substrates

Deposition techniques (spin coating, R2R printing)
Device testing
Encapsulation : stability study

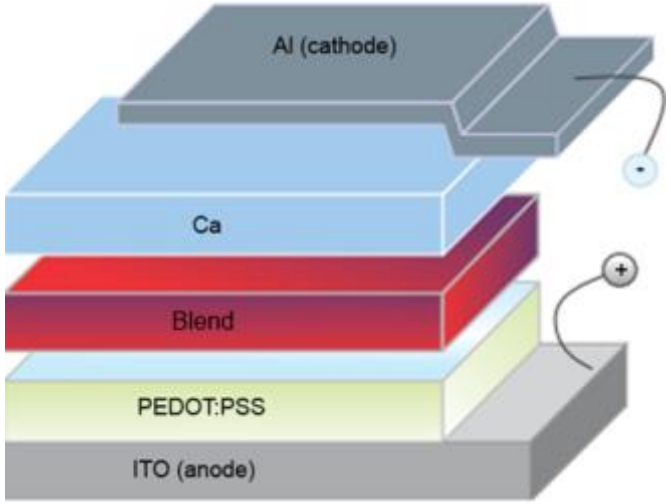
ENEA
SSPT-NANO unit

Polymer solar cells - ENEA-SSPT-NANO

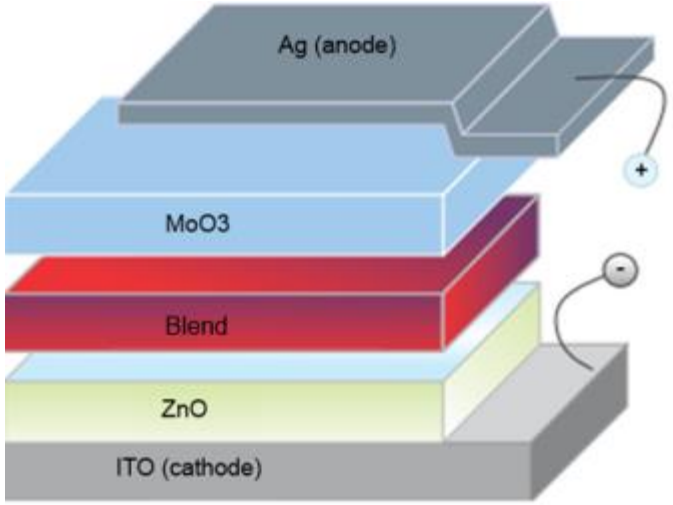
Laboratory for Nanomaterials and Devices

OPV:Device architecture

STANDARD



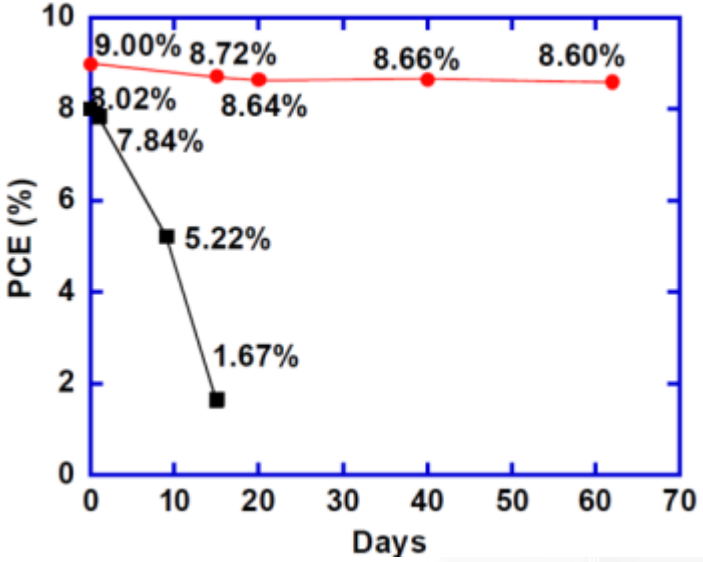
INVERTED



DISADVANTAGES:

the cathode (Ca/Al) is susceptible to degradation by oxygen and water vapor

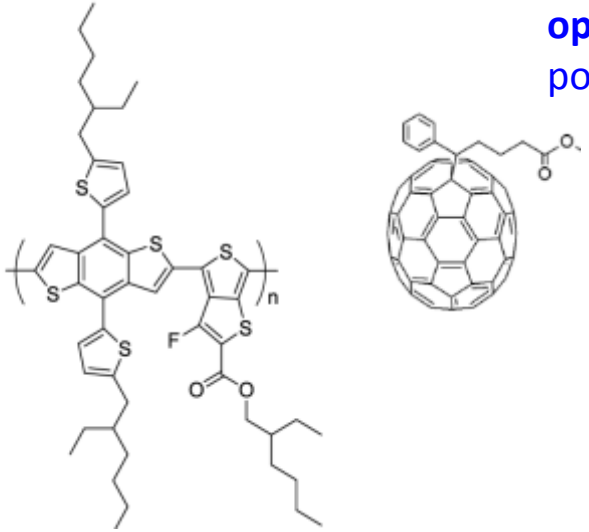
PEDOT:PSS (HTL) is hygroscopic and acidic producing fast degradation of ITO



Polymer solar cells - ENEA-SSPT-NANO

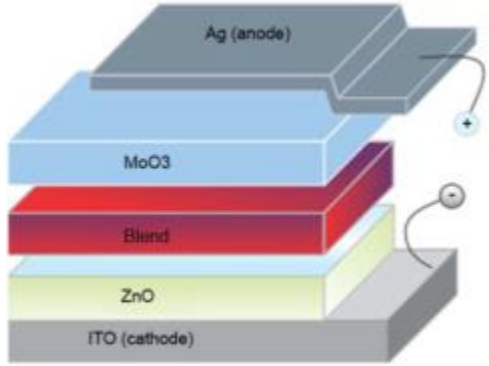
Laboratory for Nanomaterials and Devices

Polimeric Blend
PTB7-Th:[70]PCBM

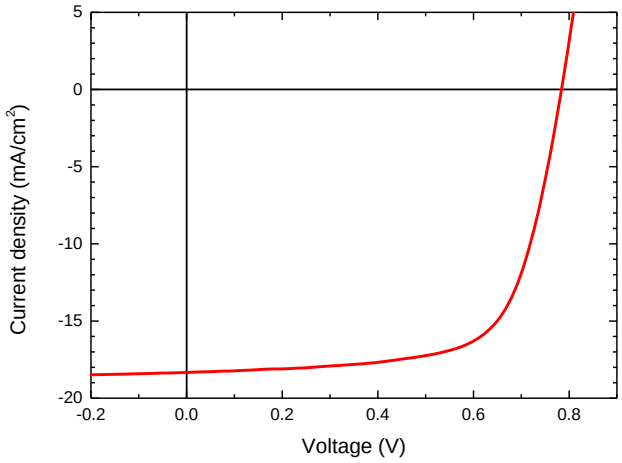


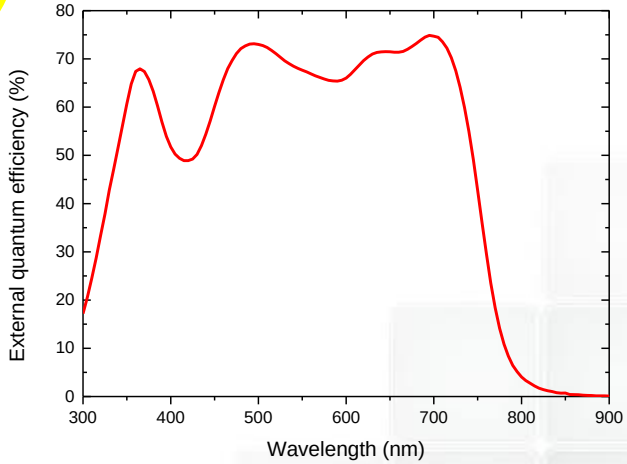
OPV :Device architecture

optimized ZnO film tested as Electron Transport Layer with a donor polymer in a single junction PSC with **inverted architecture**



PCE = 10.1 %
FF = 69.3 %
J_{sc} = 18.0 mA/cm^2
V_{oc} = 792 mV
20mm^2





Still investigating to improve the morphology of the layer to further improve the performance

PV Component & Systems

Main research topics

- PV, CPV and solar
- Power conversion for RES
- Hybrid solar photovoltaic-thermal plant
- Building integration (BIPV and BAPV)
- Thermal and electric storage
- Test and qualification of PV and CPV components
- Distributed generation and Smart Grids
- Nearly Zero Energy buildings (NZEB's)





PV Component & Systems

Advanced services for industries

- Innovative PV components design and development
- Power conversion design and development
- Modules qualification tests
- BOS components tests
- Solar plants performances measurements
- Plant sites characterization





ZOOMING IN LABORATORIES

Solar cell characterization laboratory (indoor)
Efficiency tests over concentration solar cells

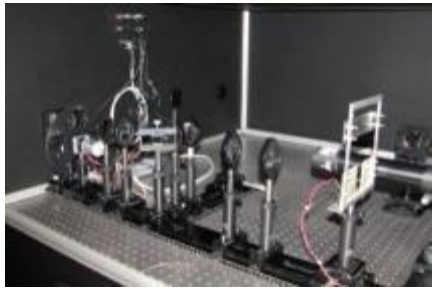
Photovoltaic module characterization laboratory (indoor)
Accredited laboratory by ACCREDIA

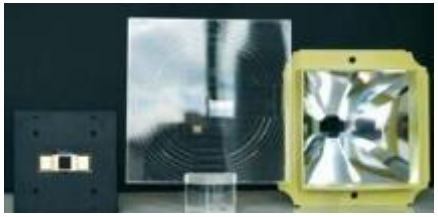
Photovoltaic receiver and module characterization laboratory (outdoor)
Energy performance tests

DMPPT DC-DC converter (indoor)
Design and energy performance tests

ZOOMING IN LABORATORIES

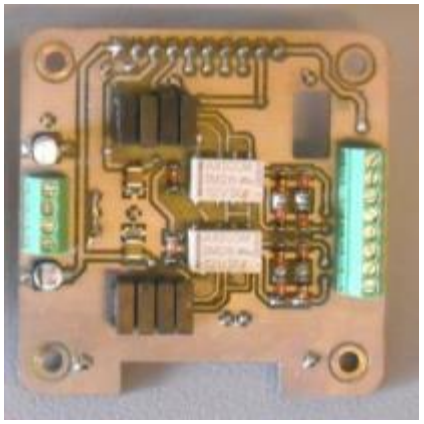
Optical components characterization laboratory (indoor)
Optical efficiency tests over primary & secondary components to optimize the production parameters





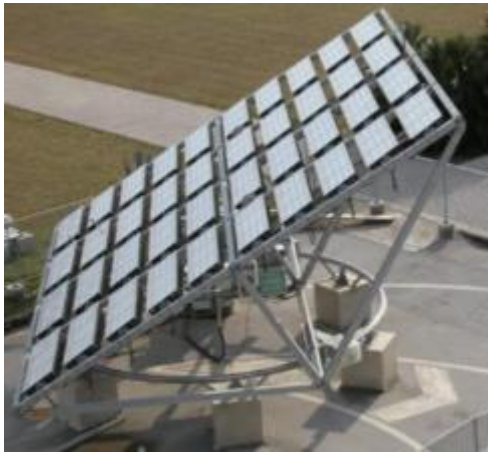
Mirror characterization laboratory (indoor)
Morphological analysis

Electronic laboratory (indoor)
Design and realization of printed circuit board (PCB)



Heat storage laboratory (indoor)
Performance test on components and control and management algorithms

ZOOMING IN LABORATORIES







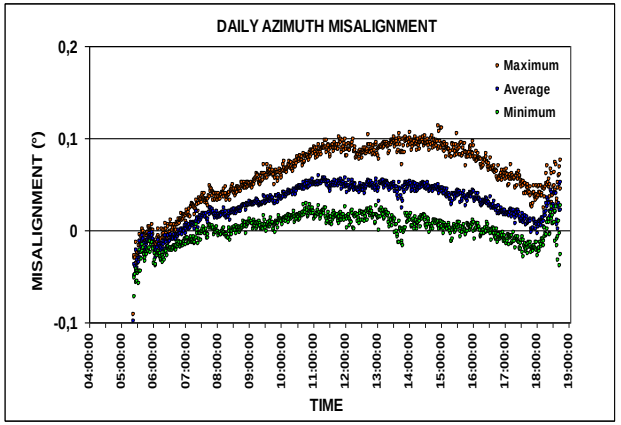



ECOSOLE PROJECT

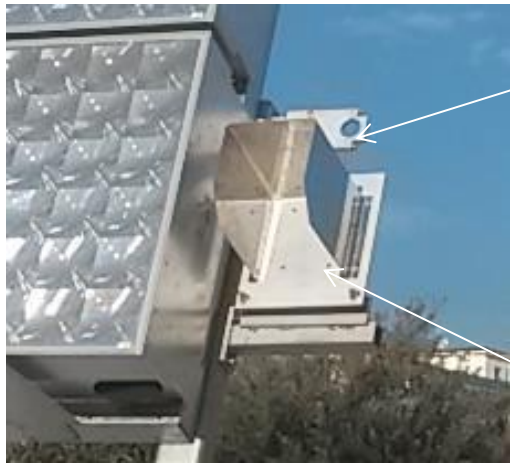
coordinated by BECAR-Beghelli, ENEA, BGU , UPM , TECNALIA scientific Partners

ENEA: Development of experimental equipment and operative procedures to carry out a complete performance analysis of the small power ECOSOLE prototype installed at ENEA in Portici

opto-electronic devic installed parallel on tracking surface to verify azimuth and altitude misalignment – vs- tim



pyrheliometer on the tracker to characterize the effective DNI incident on the modules surface (Tracking losses)

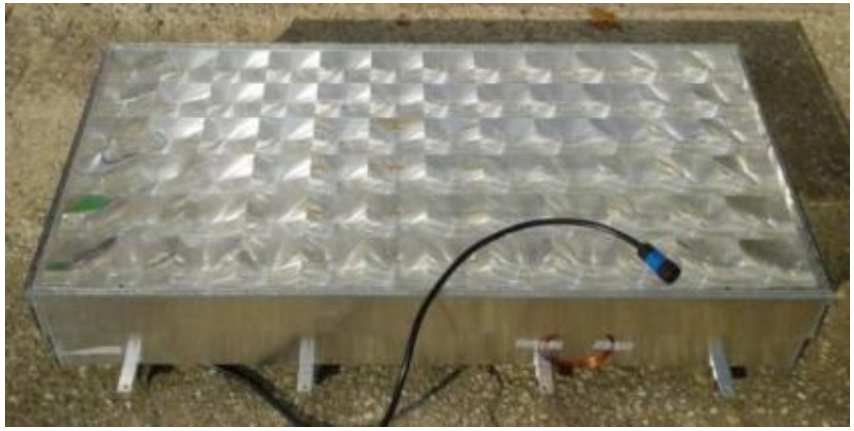


Bracket for pyrheliometer

Plate for OED

ECOSOLE PROJECT

Modules features:



- ✓ Geometrical concentration ratio: **940X**
- ✓ Optic: **SoG Fresnel lens + prismatic quartz** element
- ✓ **Triple junction** commercial **solar cells** from different manufacturers: EMCORE, AZUR SPACE, SOLAR JUNCTION
- ✓ Geometrical layout: array of **6x12** receivers
- ✓ Housing realized in **aluminum thin sheet**

Tracker features:

- ✓ Modules are arranged on 4 pre-calibrated maxi-modules
- ✓ Motion: two perpendicular series connected slewing drives with brushless motors
- ✓ Hybrid tracking algorithm using the sun ephemeris and a sun camera: the tracking is adjusted in order to reach the maximum module power output
- ✓ The tracker panel can turn upside down for cleaning and to protect the parquet from sand storm and from the moisture condensation effects

SOLAR THERMODINAMIC & THERMAL

IN ENEA

Brief history of ENEA CSP Solar Technology

2001 To 2003

- Project Start-up Government Role
- Lab R&D: Prototype Design

2004 To 2007

- PCS Facility: Prototype Operation start-up
- Components test and qualification

2008 To 2009

- Industrial Demo plant Industrial Role
- Demo design and construction

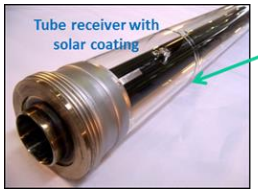
2010

- Start-up demo plant

Main Activities

Thermal and Thermodynamic Solar Division mainly operates to promote and carry out different research strategic lines, and innovation projects, which are quite relevant for the development of CSP technology in Italy and abroad:

- Research: new solution for thermal fluid (new molten salt mixtures, gas, water), critical components (receiver system, steam generator, storage system), and solar plant configuration(power generation, hybrid plants, desalinization, process heat, solar cooling, solar fuel)
- Advanced services: Support to industry for components development, testing and qualification in ENEA facilities; support to engineering firms and utilities for design and construction of power plant of different size and for various applications.





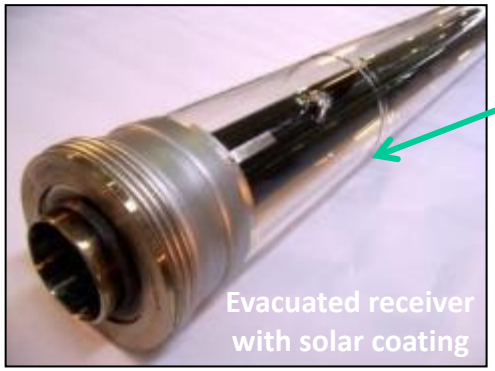
Main Activities

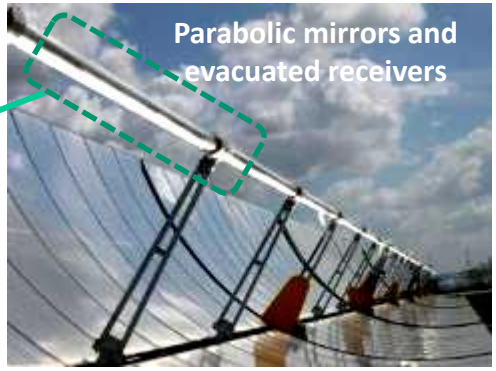
- Transfer Technology : dissemination and transfer of research results to industry and exploitation for production purposes
- Training and information: activities aimed at broadening sector expertise and public knowledge

Solar thermal energy at low and medium temperature

- Quality and Reliability Test Laboratory for low temperature collectors
- Energy characterisation of collectors for uses at medium temperature (i.e. up to 300° C)
- Development of thermo-fluid-dynamic models for the optimisation of solar collectors, evaluation and optimisation of components for solar cooling systems

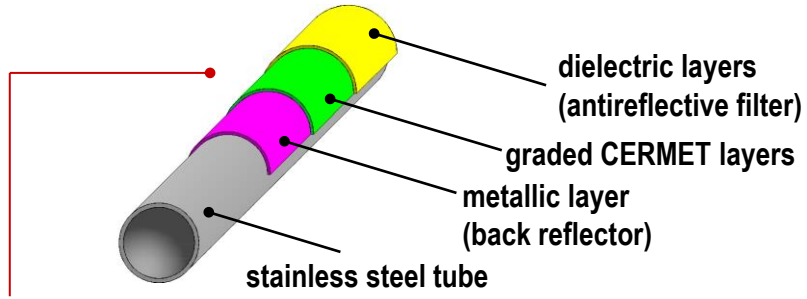
Solar coatings





Innovative technology: CERMET-based stratified thin films containing AlN-WN nano-composites, produced inside vacuum deposition apparatus by sputtering processes – **ENEA Patent**

Advantages : Maximum operation temperature (550 °C) higher than other commercial products (400 °C). Unique product in the worldwide market.



Structure of thin film based solar coating
(global thickness < 0.5 micron)

Solar coating patented by ENEA and licensed to Archimede Solar Energy (ASE, Angelantoni Group) to produce receivers for high temperature purpose.

Technological transfer of production processes

Agreement between ENEA and ASE industry to give technological support on production line : performance qualification and additional R&D activity for product improvement.

Industrial sputtering apparatus to fabricate ENEA solar coating at the manufacturing site - Massa Martana (PG, Italy)

Production yield
Up to 70.000 receivers/year

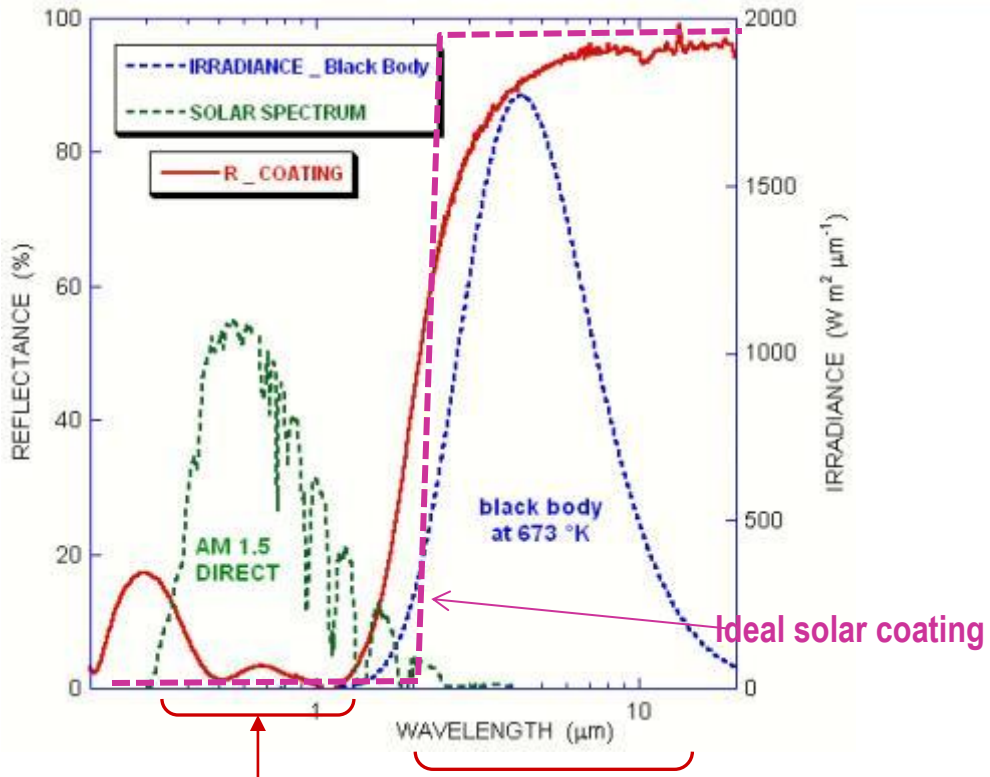
Optical Selective Solar coating :

Optical characteristic
of CERMET nano-composites

- High absorptance of solar radiation
- High transparency in infrared spectral region

Thermo-optical parameters of an efficient ENEA solar coating

- $\alpha_s > 95\ \%$
- $\varepsilon_h < 13\ \%$ *a 550 °C*



Very high solar absorptance α_s

Low thermal emissivity ε_h at the operating temperature (low thermal loss)

ENEA
International Activities & Networking

The main initiatives are implemented within the Agency in the framework of:

- **EU ACTIVITIES**:
  - EURATOM;
  - Projects funded by the EU
  - EERA-European Energy Research Alliance
  - European Technology Platforms
  - RTD Framework Programme Committees
  - Strategic Initiatives
- **BILATERAL COOPERATION**
- **MULTILATERAL COOPERATION.**

Solar Energy in ENEA: R&D Contacts

SOLAR THERMODINAMIC & THERMAL

Eng. Tommaso Crescenzi
DTE-STT

Components and Solar Plants Development lab
Eng. Alessandro Antonaia DTE-STT-SCIS

Engineering of Solar Technologies Laboratory
Eng. Antonio De Luca DTE-STT-ITES

PHOTOVOLATICS and SMART NETWORK

Dr. Ezio Terzini
DTE-FSN

Innovative Device Laboratory-DIN
Dr. Paola Delli Veneri DTE-FSN-DIN

Photovoltaics Technologies Laboratory - TEF
Dr. Eng Mario Tucci DTE-FSN-TEF

Photovoltaic Systems and smart network lab - FOSG
Dr, Eng. Giorgio Graditi DTE-FSN-FOSG

TECHNOLOGIES AND MATERIALS FOR THE SUSTAINIBILITY

Dr. Dario Della Sala
SSPT*-PROMAS

Nano-materials and Organic devices laboratory
Eng Carla Minarini SSPT*-PROMAS-NANO

*SSPT- Territorial and Production Systems Sustainability Department

Email : name.surname@enea.it

A European Project supported through the Seventh Framework Programme for Research and Technological Development

Grant agreement no: 609788

CHEETAH

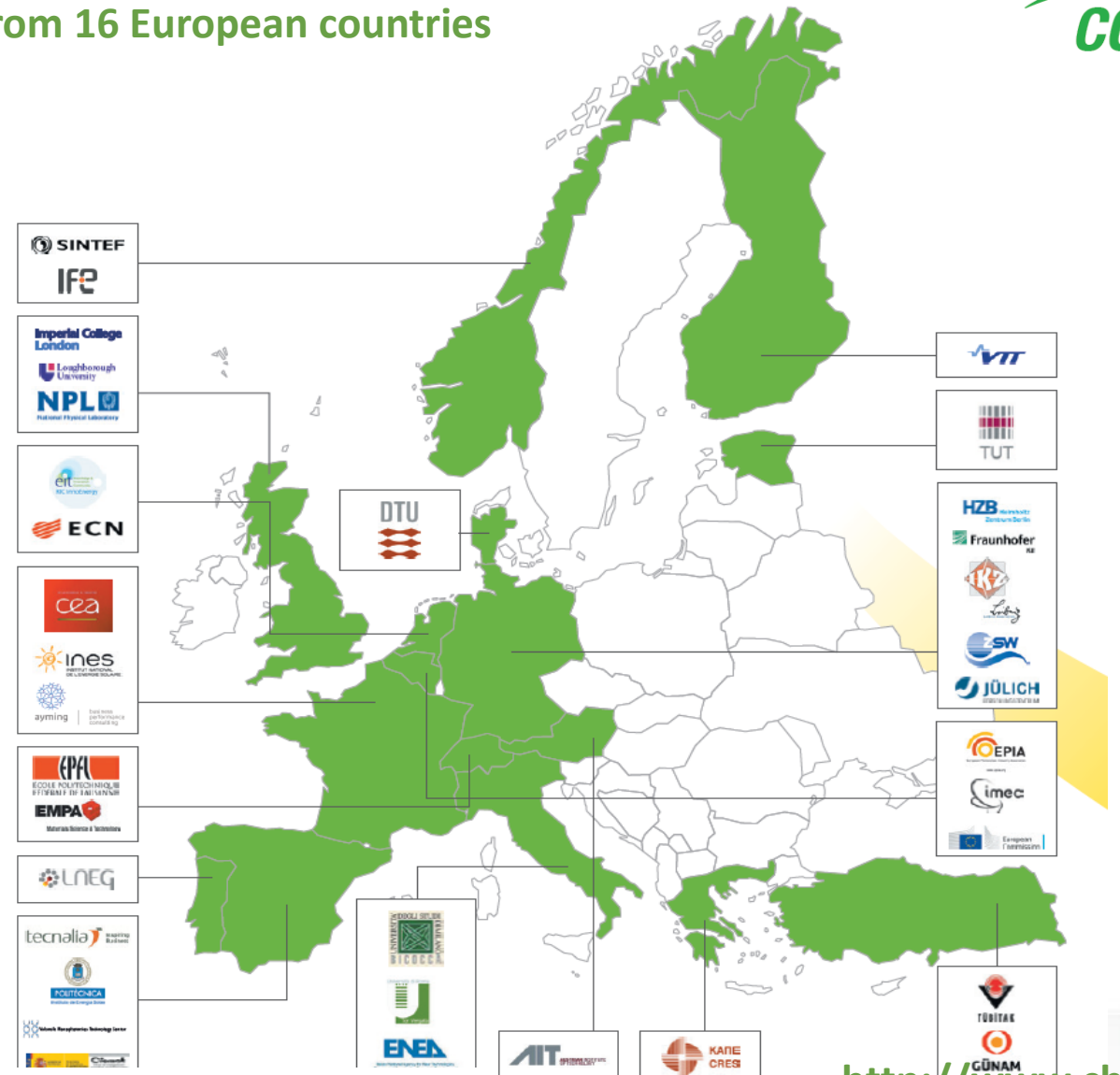
http://www.cheetah-project.eu/

Cost-reduction through material optimisation and Higher EnErgy outpuT of solAr pHotovoltaic modules joining Europe's Research and Development efforts in support of its PV industry

THEME [ENERGY.2013.10.1.5] [Integrated research programme in the field of photovoltaics]

34 partners from 16 European countries

CONSORTIUM



A European Project supported through the Seventh Framework Programme for Research and Technological Development

http://www.cheetah-project.eu/

OBJECTIVES

TECHNICAL OBJECTIVES / STRATEGIC ORIENTATIONS

Use of less, cheaper and sustainable materials

Increase of overall performance

CHEETAH
EERA-PV
+ SolarPower Europe
+ KIC InnoEnergy

TOPICS

4 main topics:
- Silicon wafers and cells
- Thin-film PV
- Organic PV
- Module technology

3 secondary topics:
- Building Integrated PV
- Concentrated PV
- Novel PV technologies

ACTIVITIES

Research Activities ⇨ technology developments

Fostering long-term European cooperation

Accelarating the transfer to PV industry

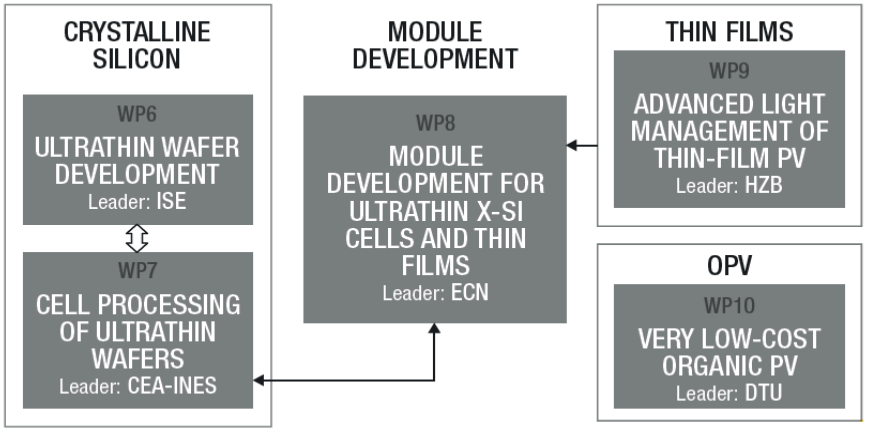
WORKPLAN

WP1
PROJECT MANAGEMENT
Leader: ECN

Coordination activities: developing the basis for long-term research and giving access to the knowledge to researchers and industry

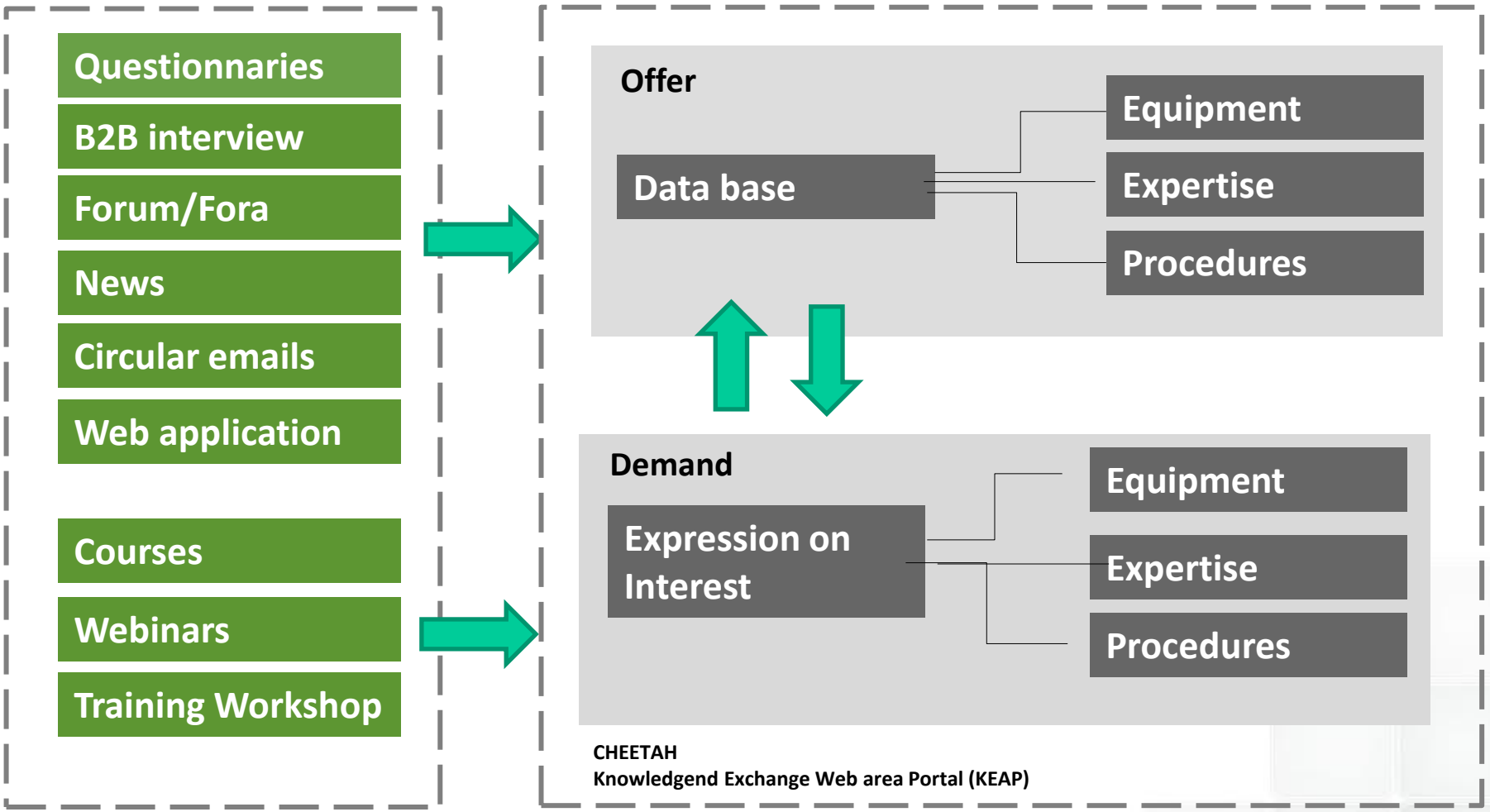
- **WP2** FOSTERING THE USE OF EXISTING FACILITIES AND EXPERTISE — Leader: ENEA
- **WP3** MOBILITY AND INTERNATIONAL COOPERATION ACTIVITIES — Leader: HZB
- **WP4** DISSEMINATION, INTERNAL AND EXTERNAL COMMUNICATION — Leader: JÜLICH
- **WP5** ACCELERATION OF INNOVATIONS' IMPLEMENTATION — Leader: SOLARPOWER EUROPE

JRA : improving the services provided and fill in the gaps: more power with less materials



CHEETAH KNOWLEDGE EXCHANGE AREA (KEAP)

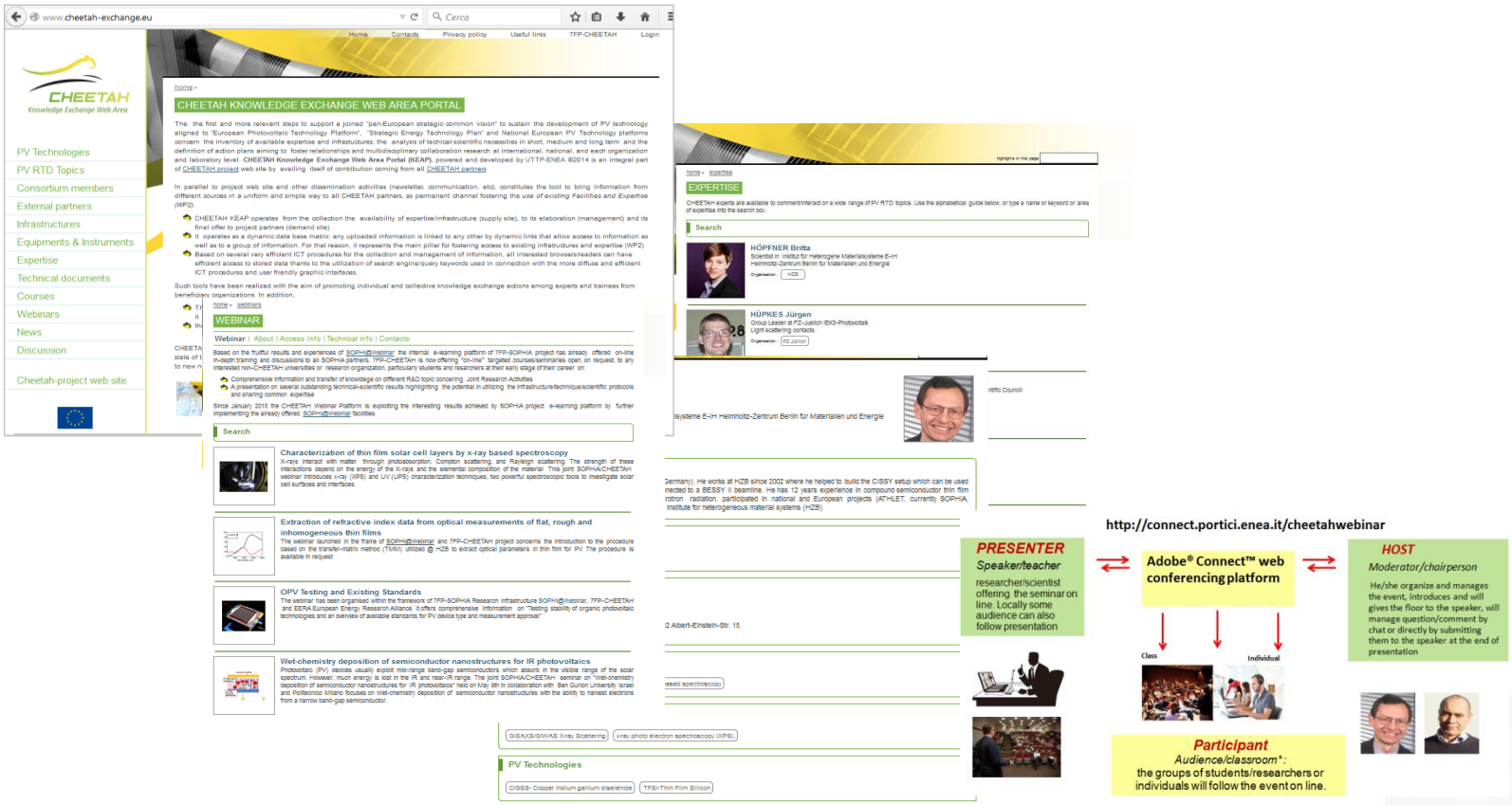
ICT TOOLS AND PROCEDURE FOR KNOWLEDGE EXCHANGE



http://www.cheetah-exchange.eu/

CHEETAH KNOWLEDGE EXCHANGE PLATFORM

http:/www.cheetah-exchange.eu



http:/www.cheetah-project.eu

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DTE Energy Technologies Department

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Fax:+39-081-7723344

E-mail:
franco.roca@enea.it

Thanks for your attention !