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

Accordo di Programma MSE-ENEA

Ministero dello Sviluppo Economico

Ricerca Di Sistema elettrico

Ricerca su celle fotovoltaiche innovative

Paola Delli Veneri

ENEA

"Energia elettrica da Fonte solare" - Roma, 27 maggio 2015

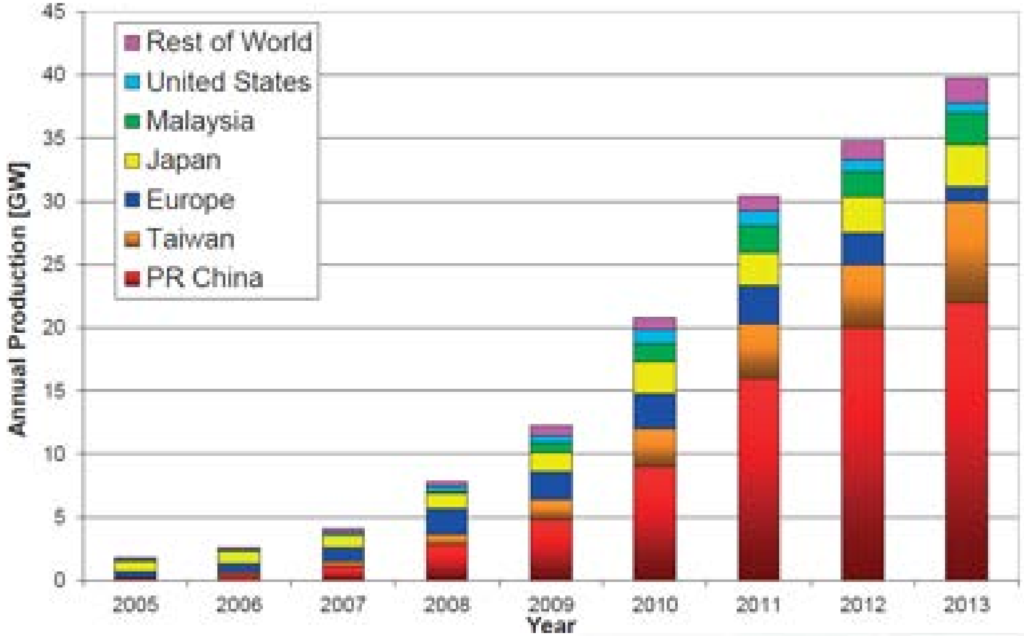
Company	Technologies	Modules delivered in 2014 (in MWp)
Trina Solar (China)	*Wafers, crystalline (mono) cells, modules*	3660
Yingliu Green Energy (China)	*Wafer, mono and multi crystalline cells, modules*	3361
Canadian Solar (Canada, China)	*Ingots, wafer, cells, modules, PV systems*	3105
Jinko Solar (China)	*Ingots, wafer, mono and multi cells, modules,*	2944
JA Solar (China)	*Mono/poly crystalline, modules*	2407
Renesola (China)	*Poly silicon wafer and modules, micro inverters*	1970
Sharp Corporation (Japan)	*Crystalline (mono, multi) and thin film Si modules*	1900
Motech (Taiwan)	*Crystl. cells (mono, multi) and modules, inverters*	1632
First Solar (USA)	*Thin film modules (CdTe)*	1500
Sun Power (USA)	*crystalline (mono, multi) cells, modules*	1254

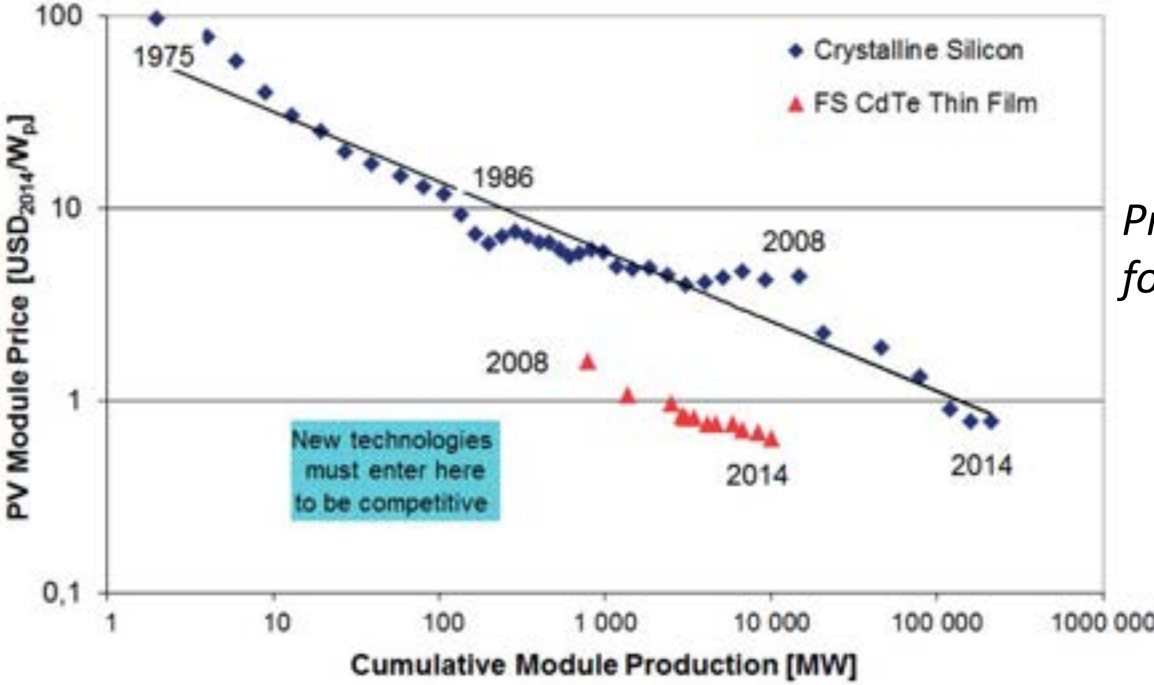
Top 10 PV modules producers in 2014

Source: EurObserver 2015

PV cell/module production

Source: PV Status Report 2014, Arnulf Jager-Waldau European Commission, DG Joint Research Centre

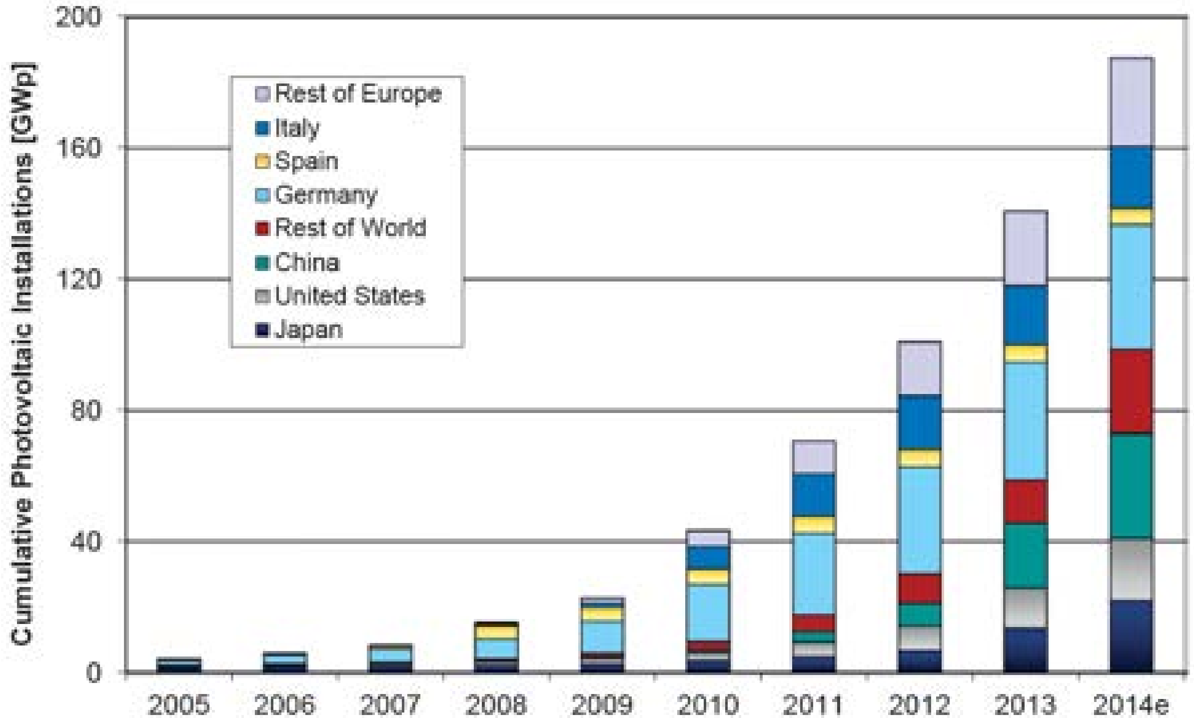




Price-experience curve for solar modules

PV system average price without financing and VAT: Eur 1400/kWp

Cumulative PV Installation from 2005 to 2014



Source: PV Status Report 2014, A. Jager-Waldau European Commission, DG Joint Research Centre

PV State of Art

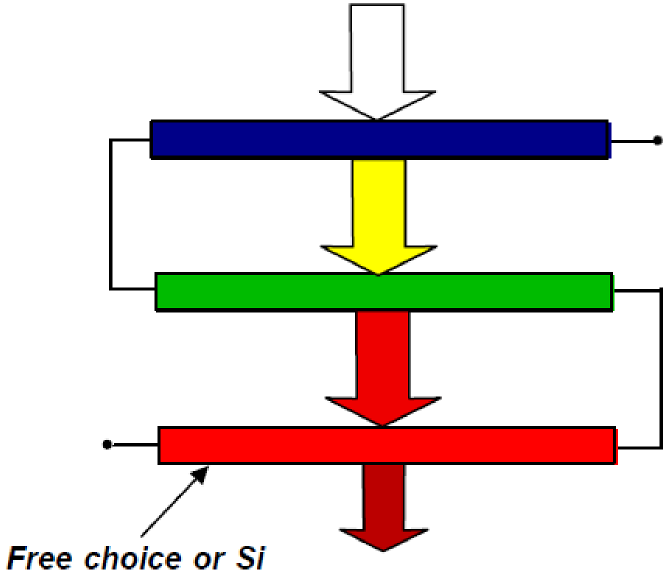
Tecnology	Efficiency (%)	Area (cm^2)	Institution
HIT (a-Si/c-Si), n-type c-Si	25,6	144	Panasonic
Si (multicrystalline)	20,8	244	Trina Solar
Thin film Si (tripla giunzione)	13,4	1	LG electronic
Thin film CIGS	21,7	0,5	ZSW
CZTSS (thin film)	12,6	0,4	IBM solution grown
Thin film CdTe	21,0	1	First Solar
Perovskite thin film	20,1	0,1	KRICT- Korea
Organic (thin film)	11,1	0,16	Mitsubishi Chemical

Martin A. Green et al., Solar cell efficiency tables (version 45),Prog. Photovolt: Res. Appl. 2015; vol 23 (1),p:1–9.

Two possible approaches to the PV Research

Development of extremely low cost PV technologies using available and not hazardous materials:

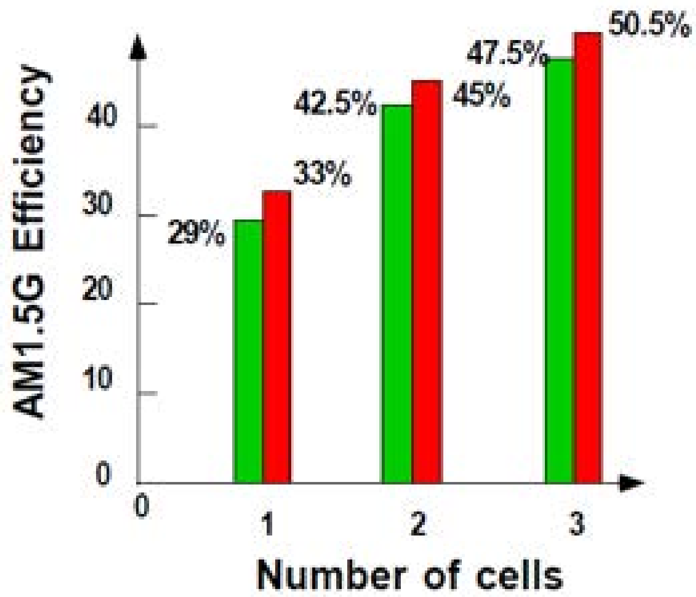
- Thin film silicon solar cells
- Thin film Cu_2ZnSnS_4 (CZTS) solar cells
- Thin film organic solar cells



Multijunction solar cells for highly efficient devices with silicon bottom cell

Silicon wafer-based tandem Cells:
The ultimate PV solution for high effciency?

Martin A. Green, Proceedings of 28th EUPVSEC, (2013), p.7.



Free choice
Si bottom cell

Bottom cell: Silicon
Top cell: ????

Present PV activities funded by MSE ➜

- Heterojunction a-Si/c-Si solar cells
- Cu_2ZnSnS_4 (CZTS) based solar cells
- Perovskite based solr cells

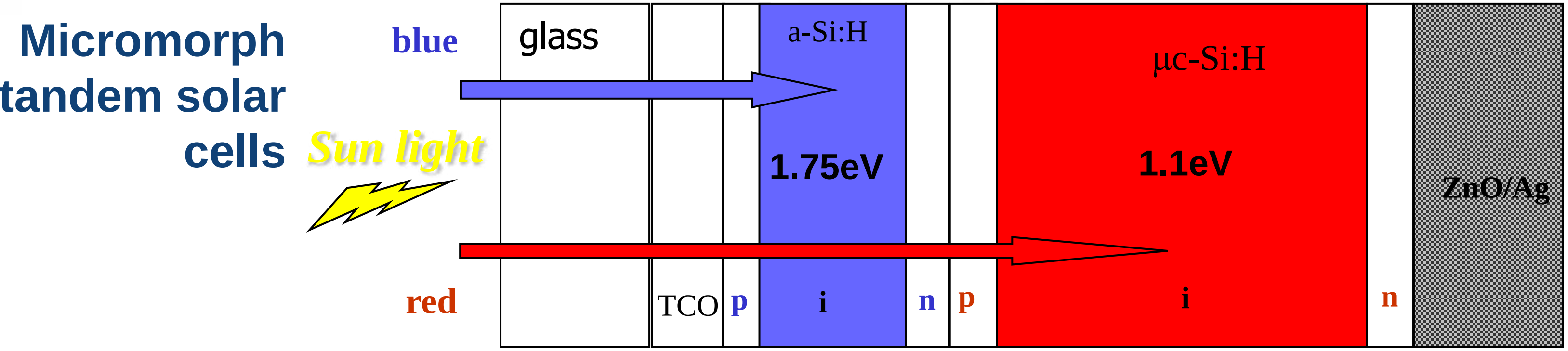
Recent past and next future in ENEA in the Research on the Electric System

- Thin film silicon solar cells
- Organic solar cells
- Perovskite based solar cell

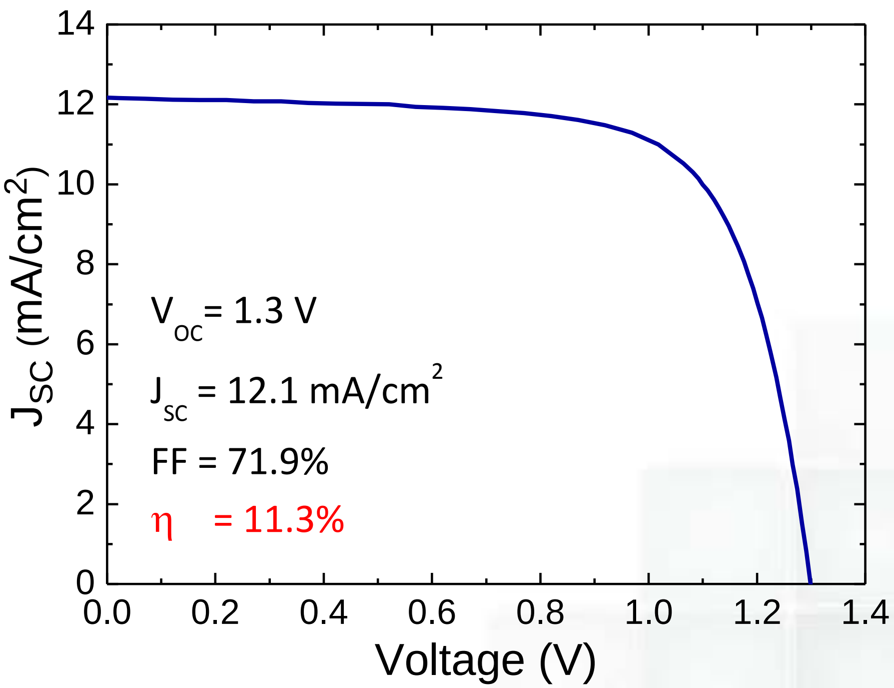
Next talks….

- Heterojunction a-Si/c-Si
- CZTS solar cells
- Light management strategies in solar cells

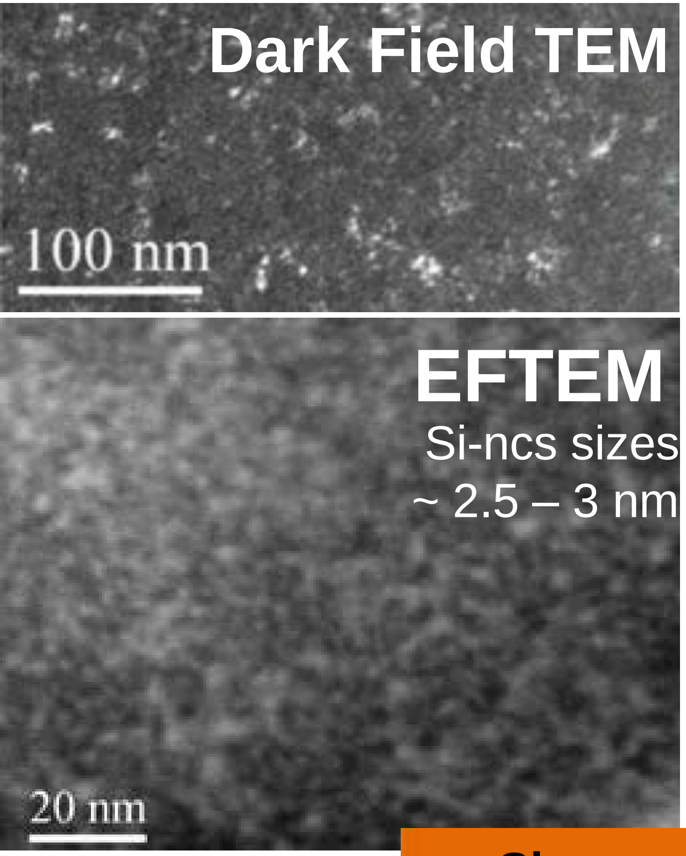
Advanced thin film silicon PV

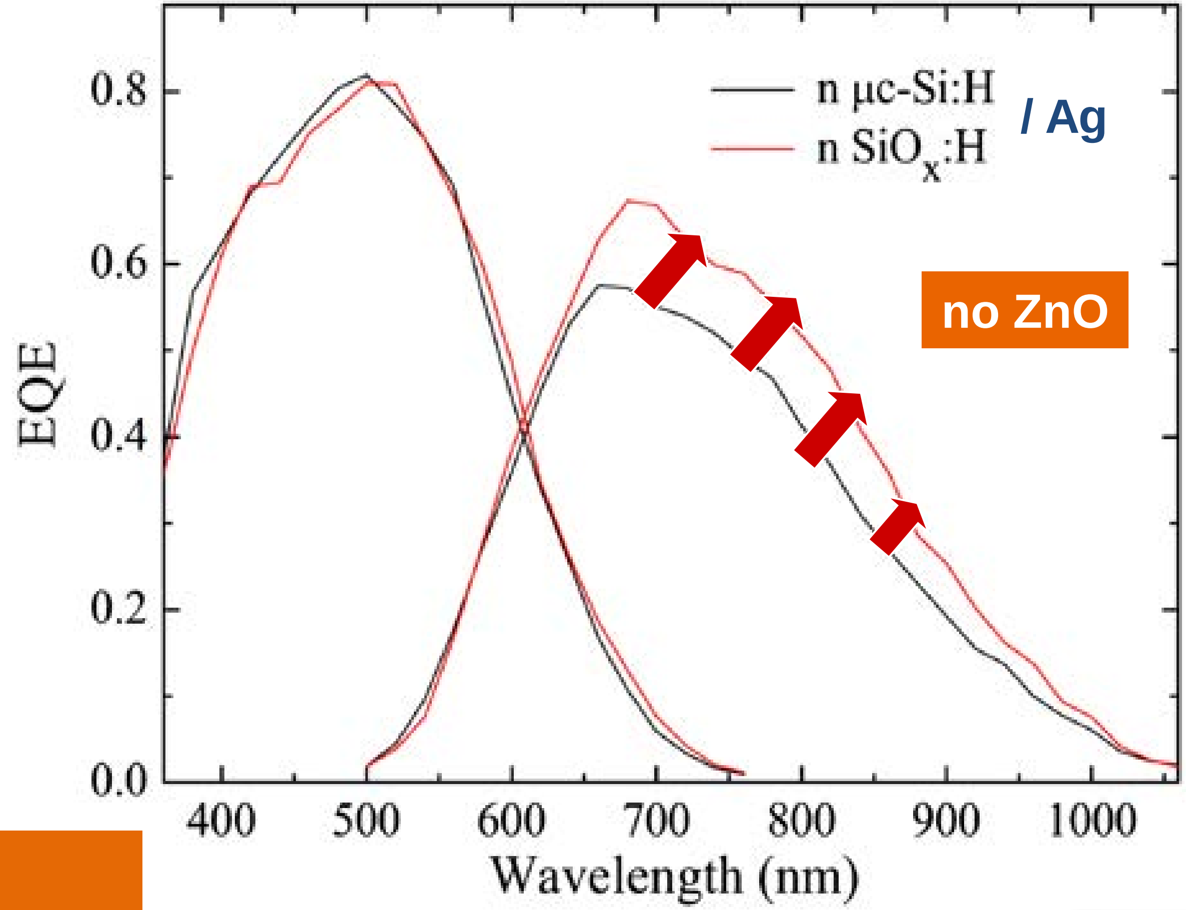


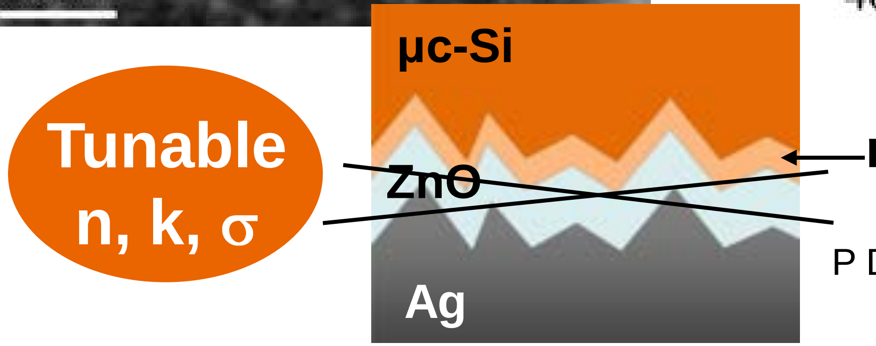
- Optimization of micromorph tandem cells by means of silicon oxide based doped materials;
- Development of innovative absorber layers for utilization in tandem cells;
- Evaluation of new architectures for an optical improvement of the thin film Si device performance



Advanced thin film silicon PV:
Development of mixed-phase n-SiO_x







n-SiO_x: n ~ 2.5

P Delli Veneri et al., Appl. Phys. Lett. 97, 023512 (2010)

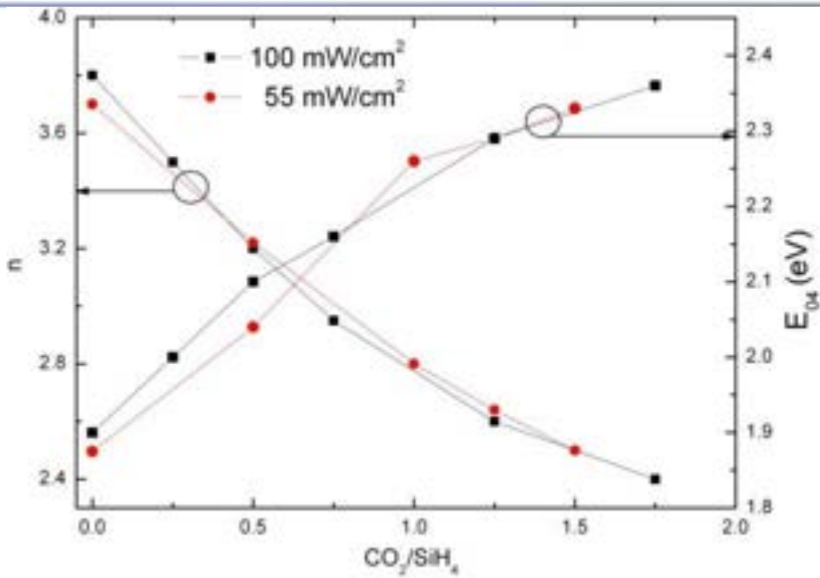
P Delli Veneri et al., Progress in Photovoltaics 21, 148 (2013)

LV Mercaldo et al., SOLMAT 119, 67 (2013)

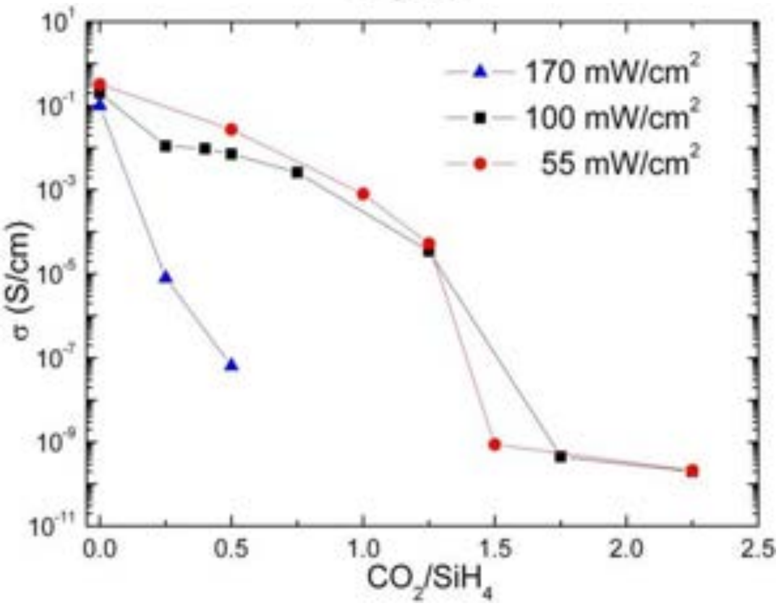
LV Mercaldo et al., SOLMAT *136*, *32* (2015)

Advanced thin film silicon PV:
Development of mixed-phase p-SiO_x:H

Optical properties



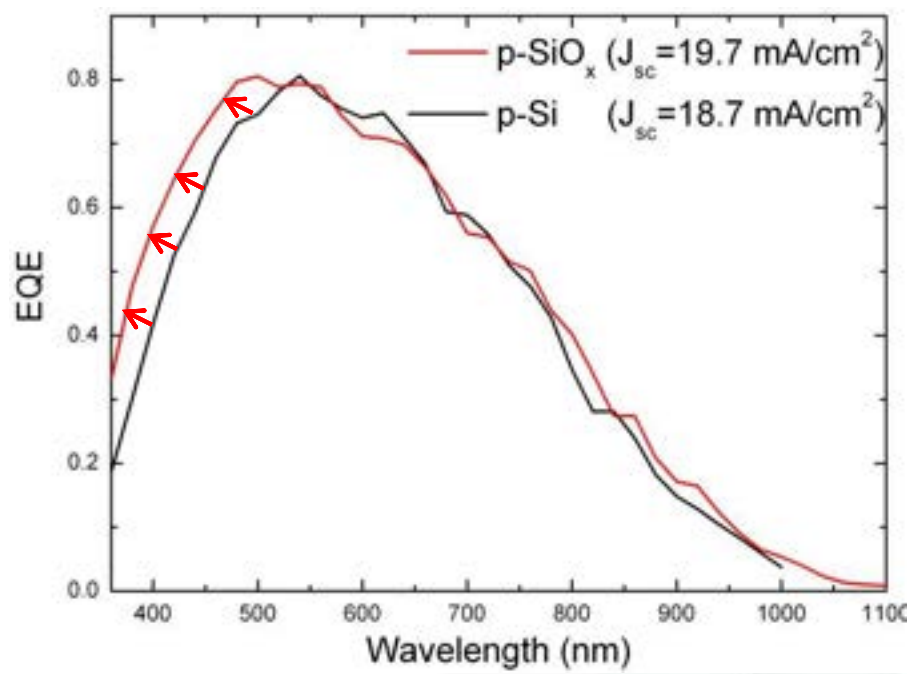
Electrical properties



The novel p-layer allows:

- **Lower absorption losses;**
- **better refractive index matching at the TCO/Si interface.**

EQE of solar cells with different p-layers

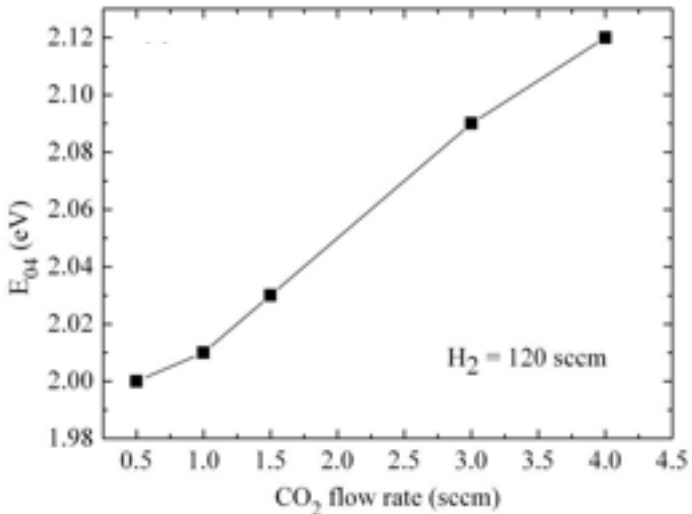


LV Mercaldo et al, Proc of 28th EUPVSEC (2013) p. 2588.

Advanced thin film silicon PV:
a-SiO$_x$:H top absorber

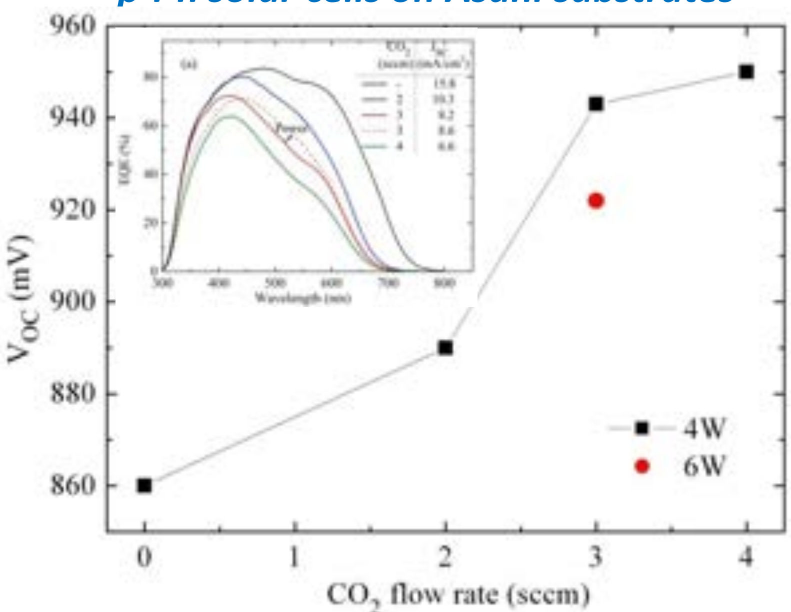
ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Optical characterization of a-SiO$_x$:H layers

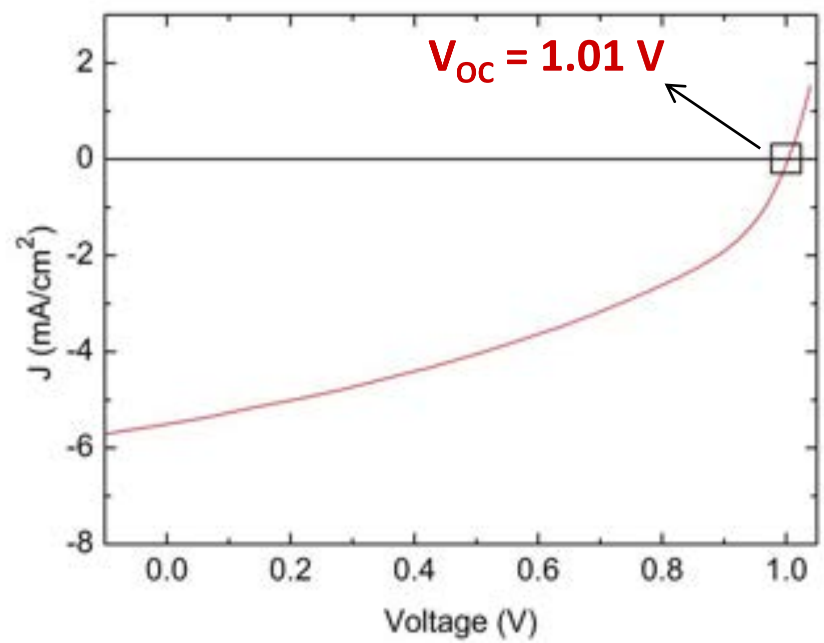


VHF-PECVD @ 40 MHz
Gas mixture: SiH_4, CO_2, H_2

p-i-n solar cells on Asahi substrates

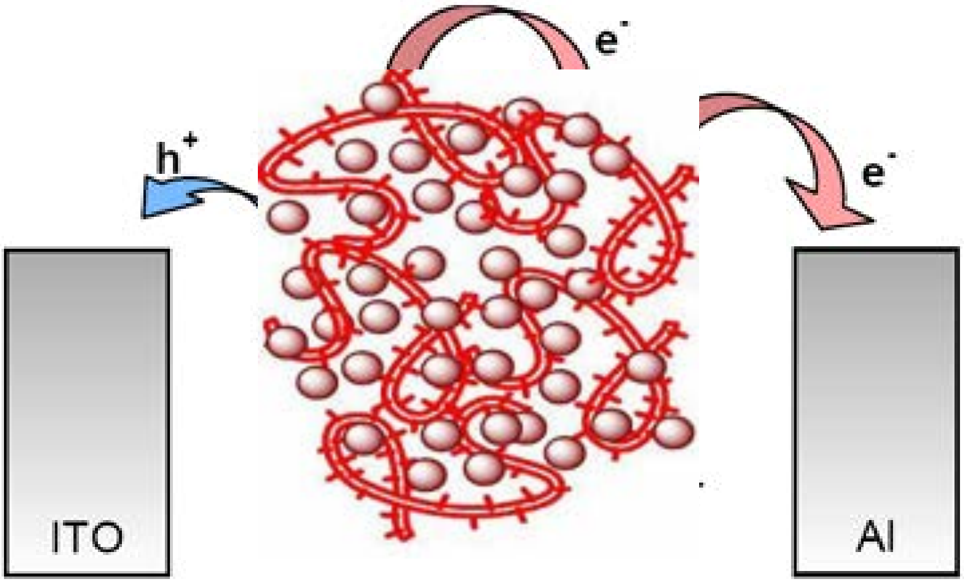


J-V characteristic of a cell grown on flat substrate (glass/ZnO)

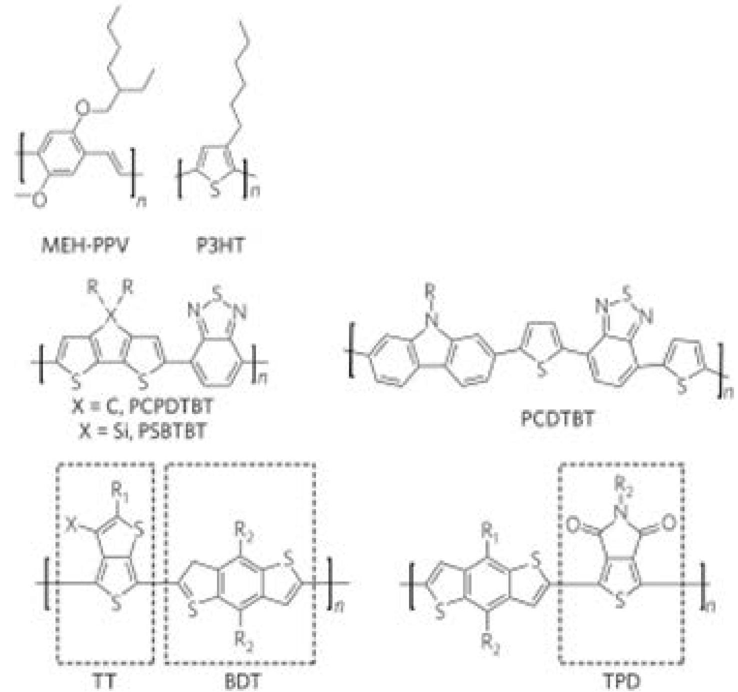


P. Delli Veneri et al, Proc of 29th EUPVSEC (2014) p. 1634.

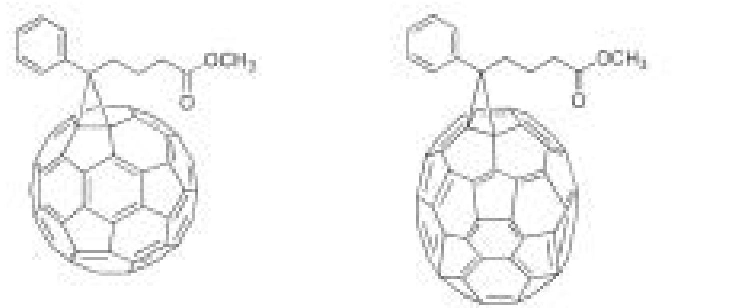
Polymer solar cells



Donors

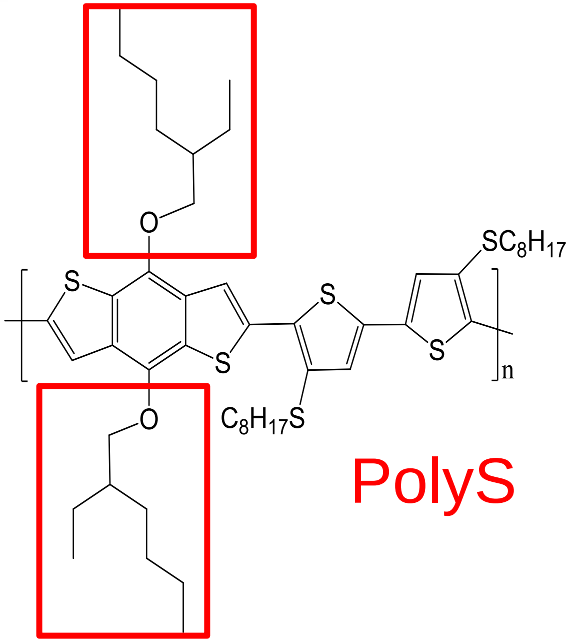


Acceptors

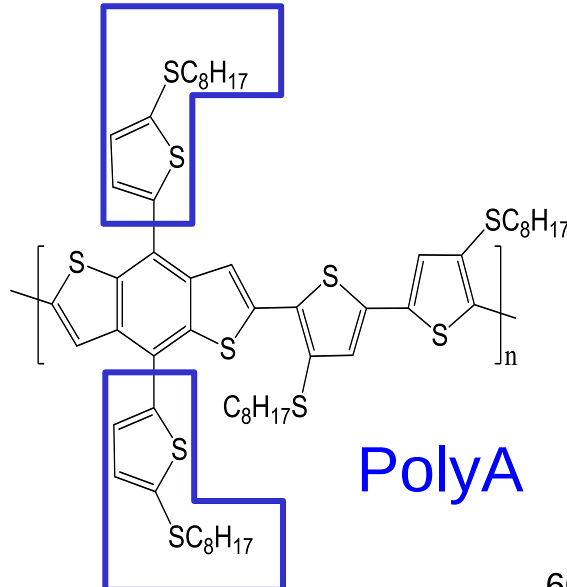


P. Morvillo et al, *Solar Energy Materials and Solar Cells*, 104, 45-52, 2012
P. Morvillo et al, *Polymer Chemistry*, 5, 2391-2400, 2014
A. Bruno et al, *Thin Solid Films*, 560, 14-19, 2014.
C. Diletto et al, Journal of Sol-Gel Science and Technology, 73, 634-640, 2015.
C. De Rosa et al, Physical Chemistry Chemical Physics, 17, 8061-8069, 2015.

Polymer solar cells



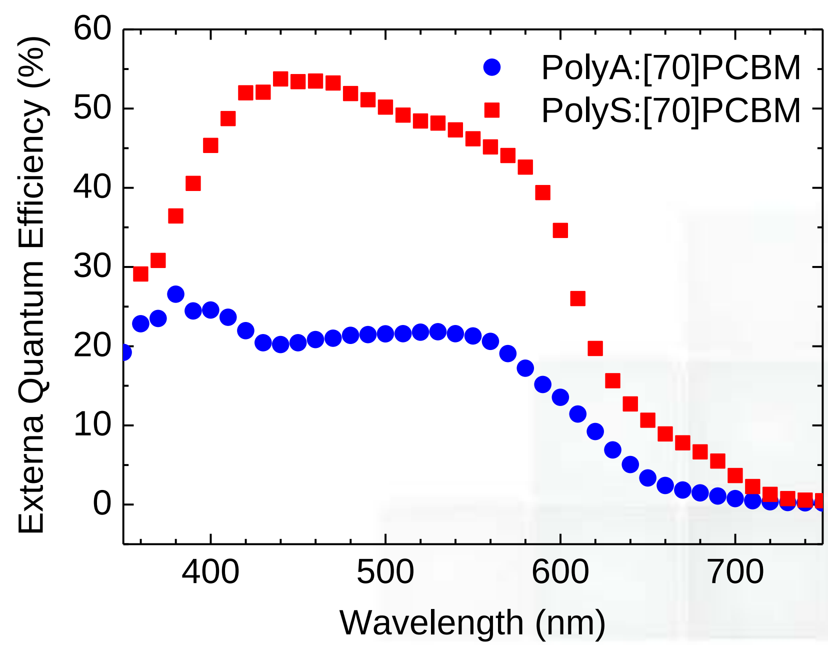
PolyS



PolyA

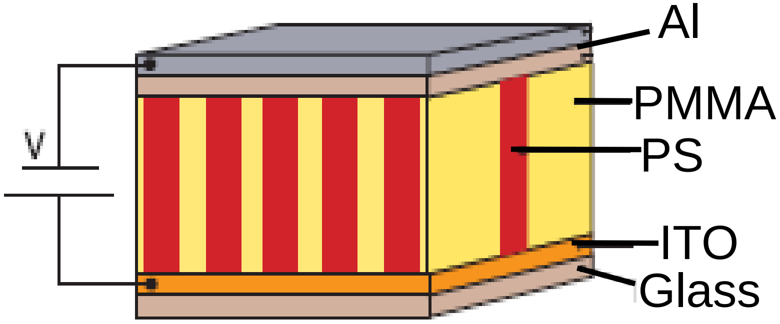
Synthesis of new copolymers to be used as donor materials in devices

Blend (1:1 wt)	PCE (%)	FF (%)	J_{sc} (mA/cm²)	V_{oc} (mV)
PolyS :[70]PCBM	2.30	48	7.0	672
PolyA :[70]PCBM	0.56	28	3.1	664

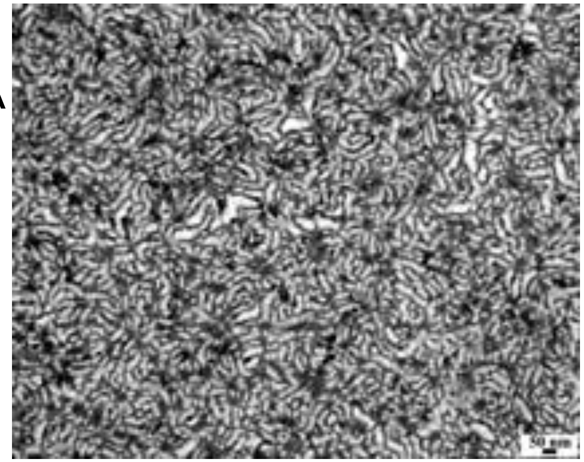


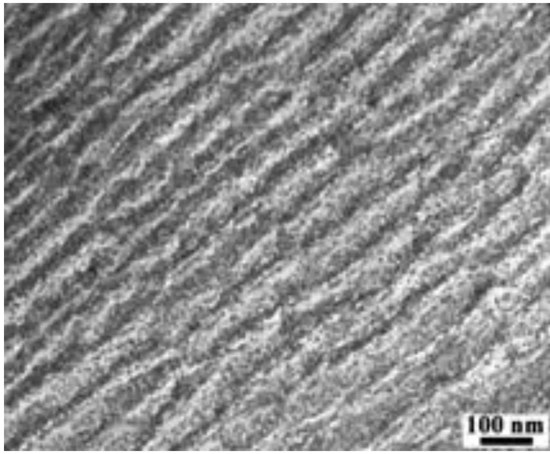
Nanostructured block copolymer to improve electrical transport

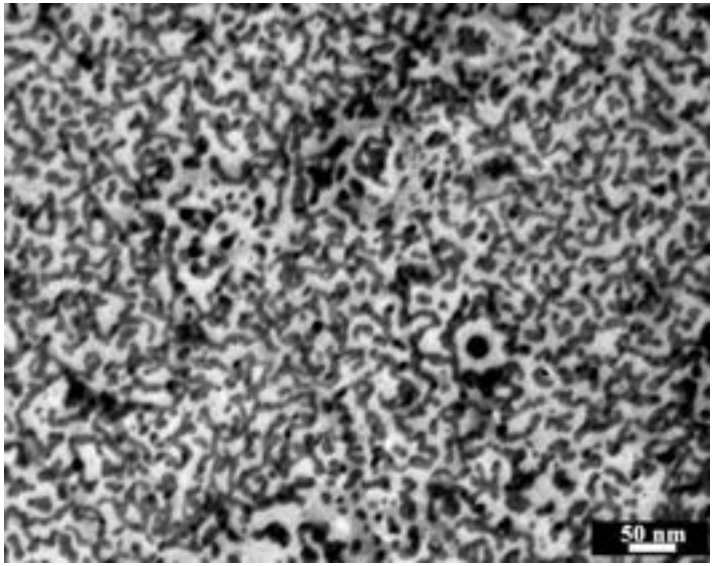
The electric field allows to align the nanostructures



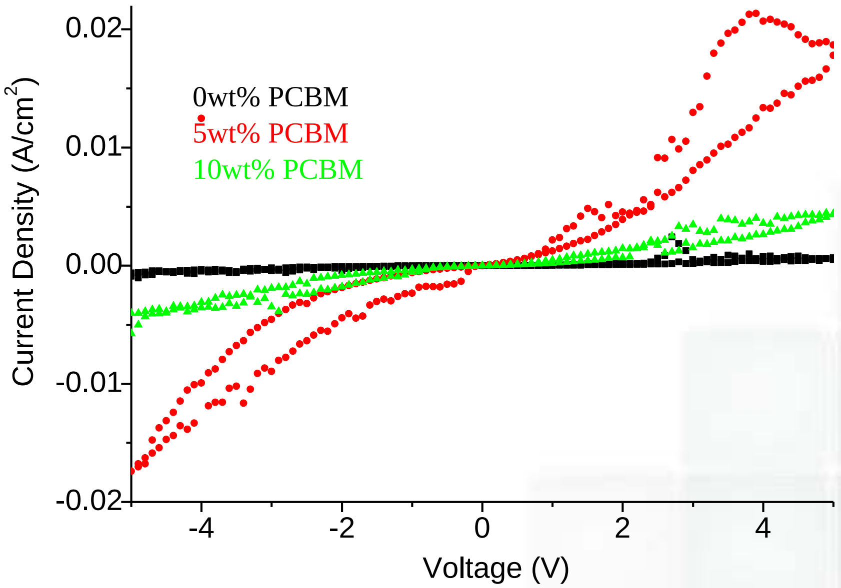
PS-*b*-PMMA



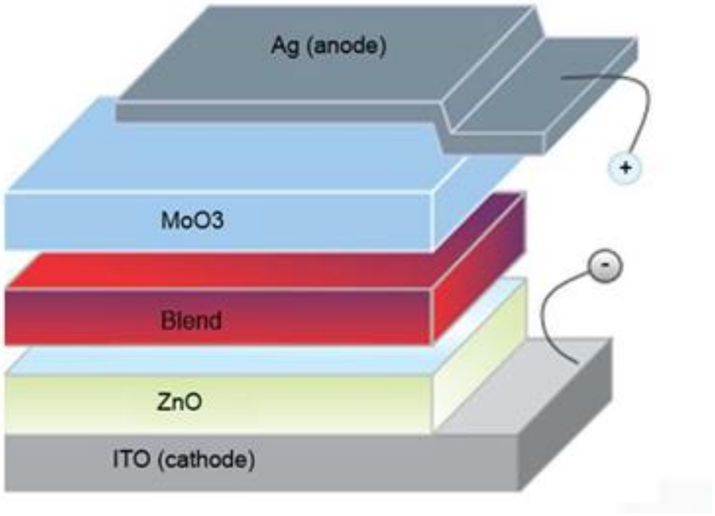


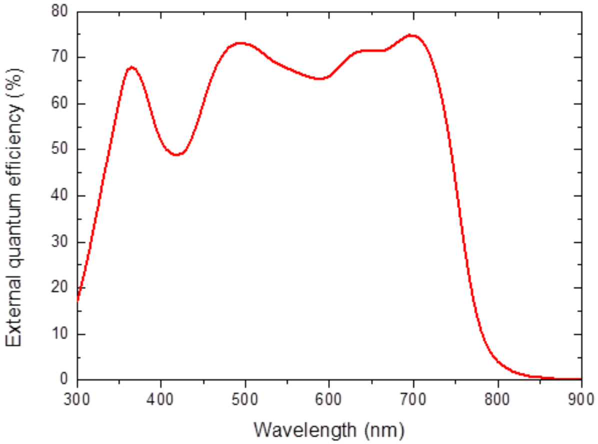


Films PS-*b*-PMMA with PCBM (5wt%)

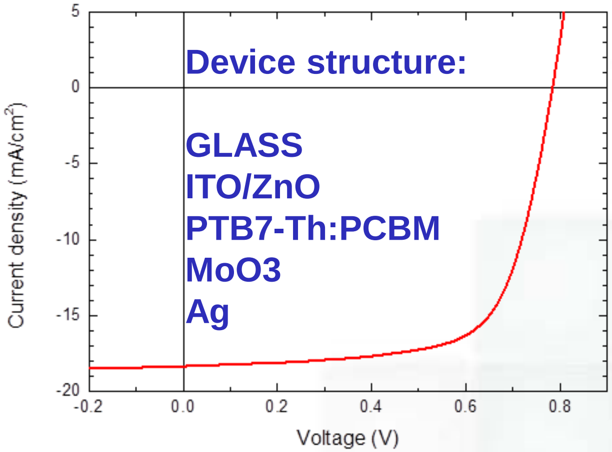


Polymer solar cells

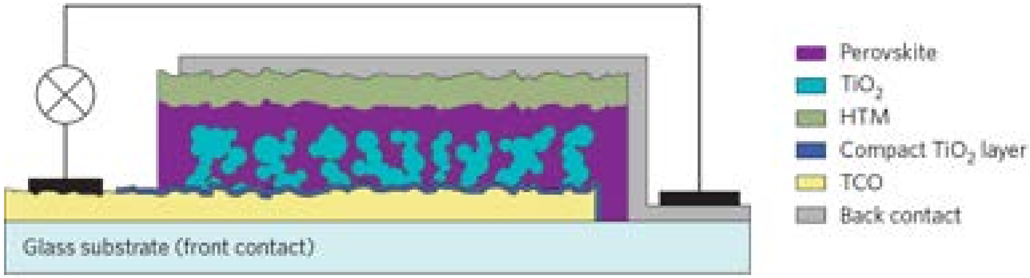


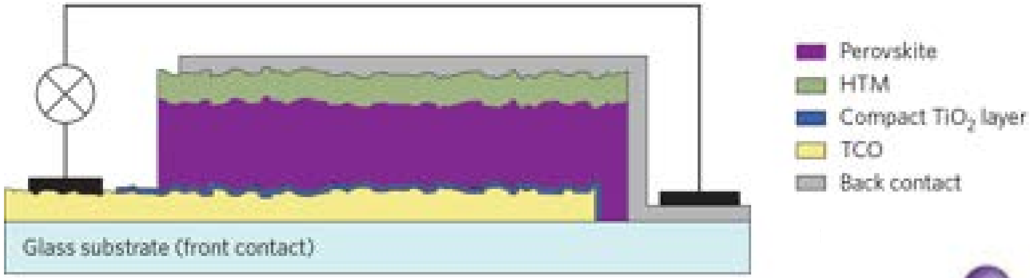


Eff= 10.1 %
FF= 69.3 %
Jsc= 18.0 mA/cm^2
Voc= 792 mV

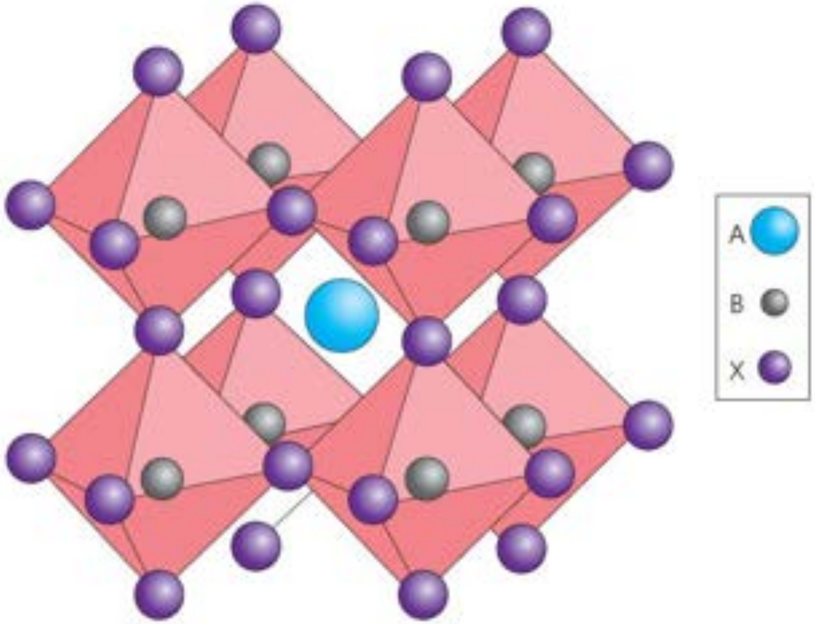


Perovskite based solar cells





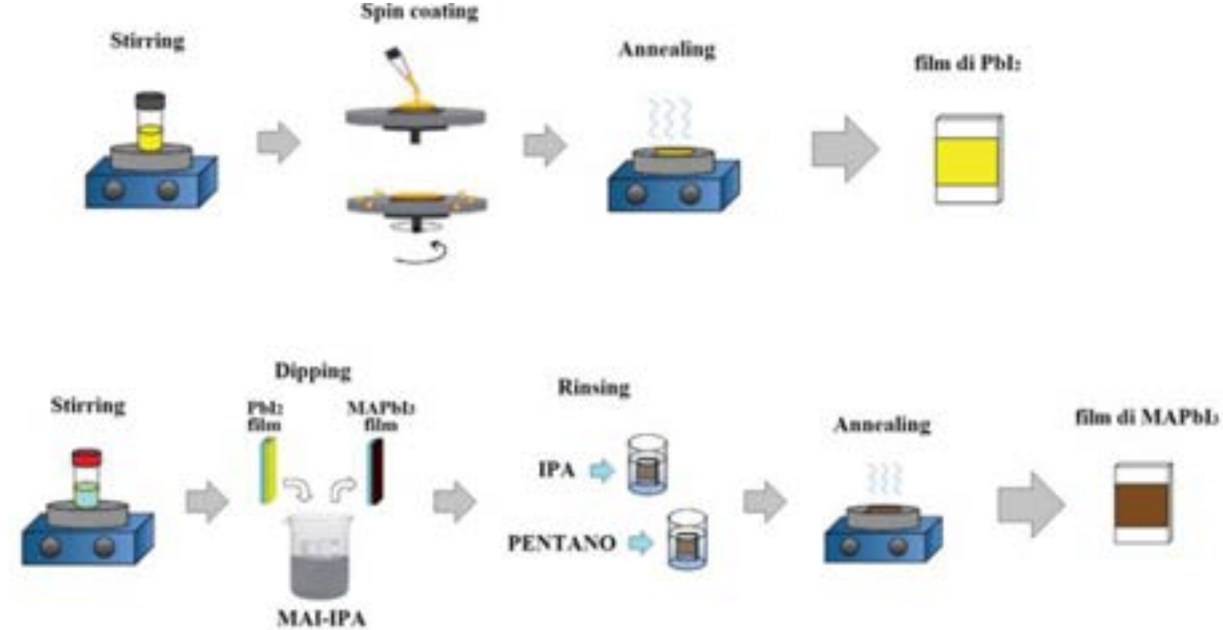
Crystal structure of cubic metal halide perovskite



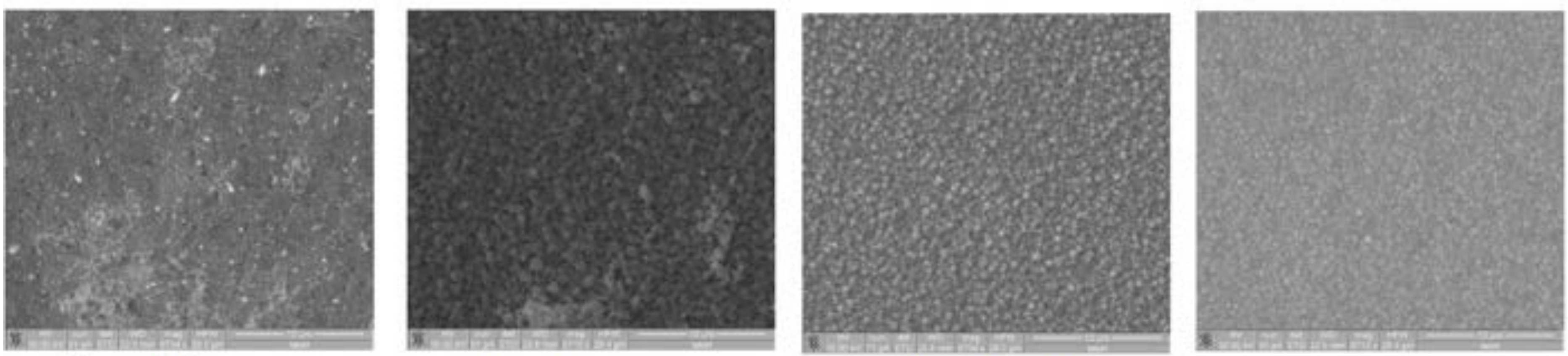
CH_3NH_3
Pb
Halogen ion (I, Cl, Br)

Perovskite solar cells

$CH_3NH_3PbI_3$ deposition

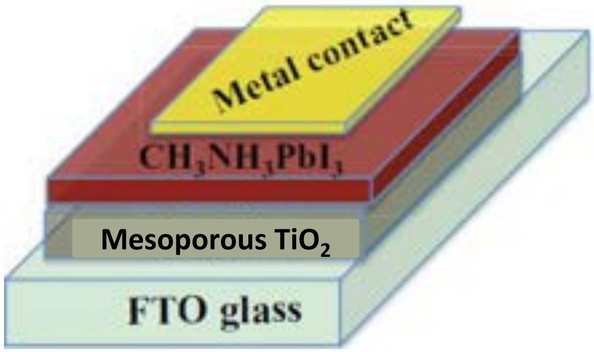


Film di perovskite depositati su diversi substrati

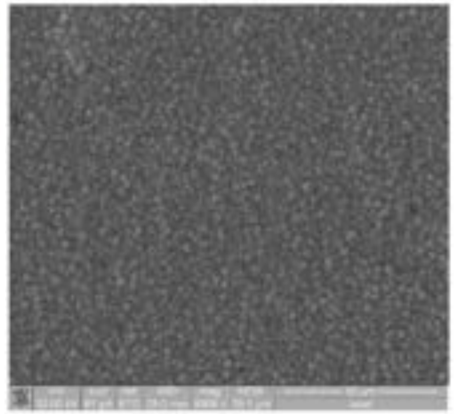


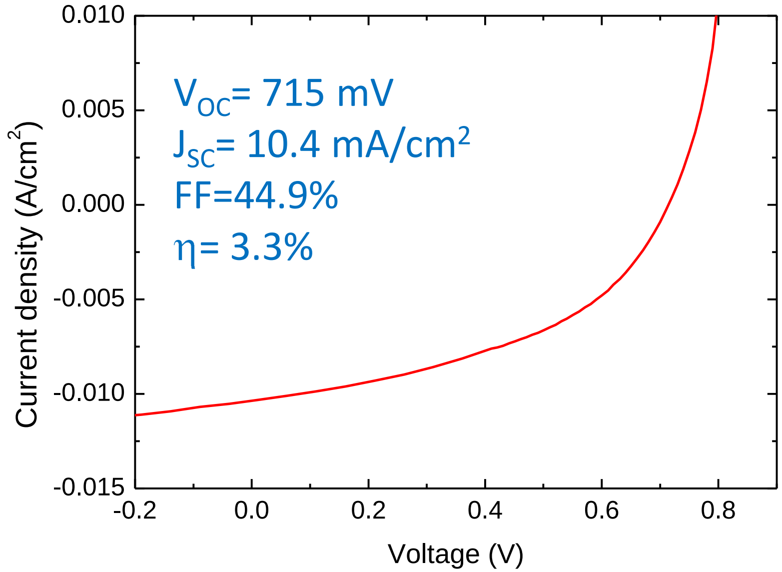
Glass FTO | Glass FTO/ZnO | Glass FTO/ITO | Glass FTO/TiO_2

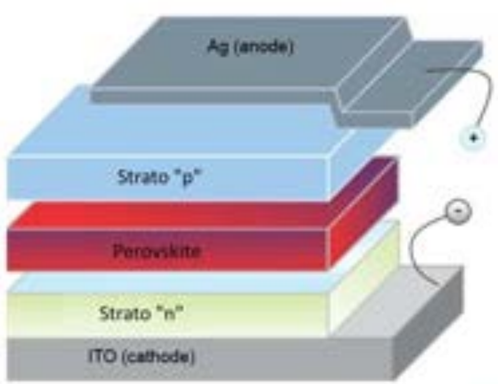
Perovskite solar cells



Schematic structure of the solar cell without a hole transporter material





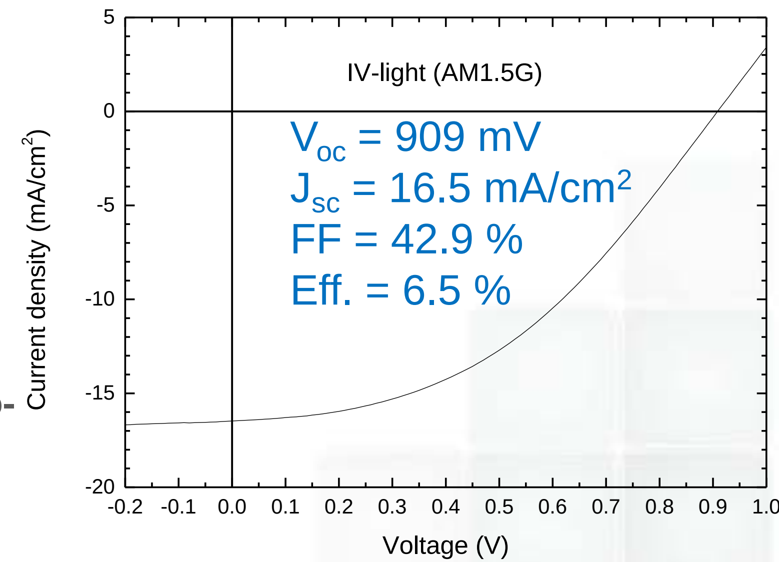


Layers under investigation:

Perovskite: $CH_3NH_3PbI_3$, $CH_3NH_3PbI_{3-x}Cl_x$

p: PEDOT:PSS, MoOx, P3HT, Spiro-MeOTAD

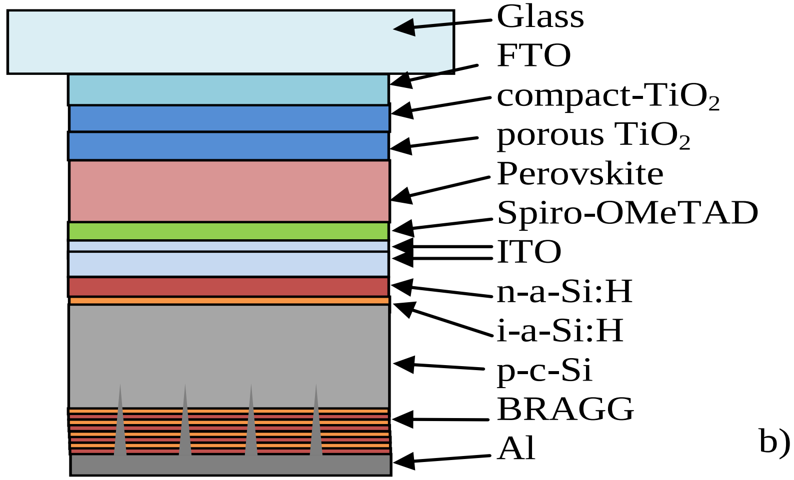
n: ZnO, TiOx, PCBM.

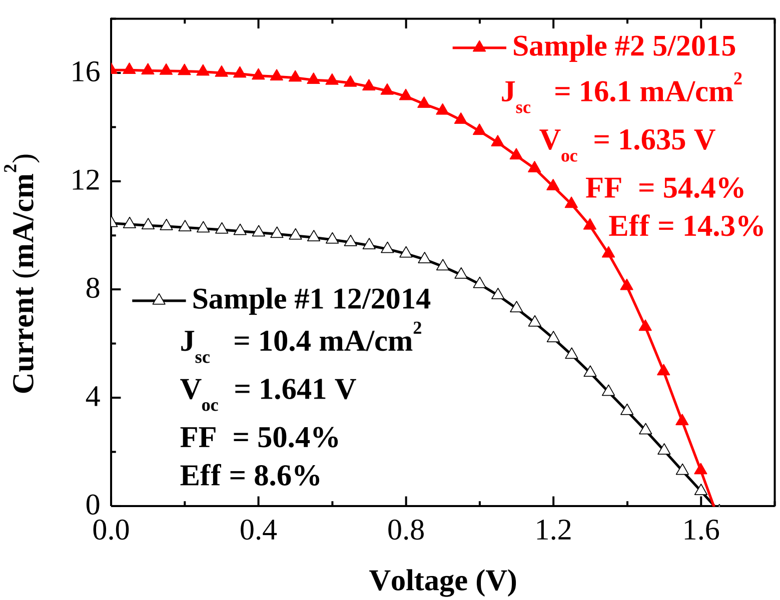


Tandem solar cell:
Perovskite and a-Si:H/c-Si Heterojunction

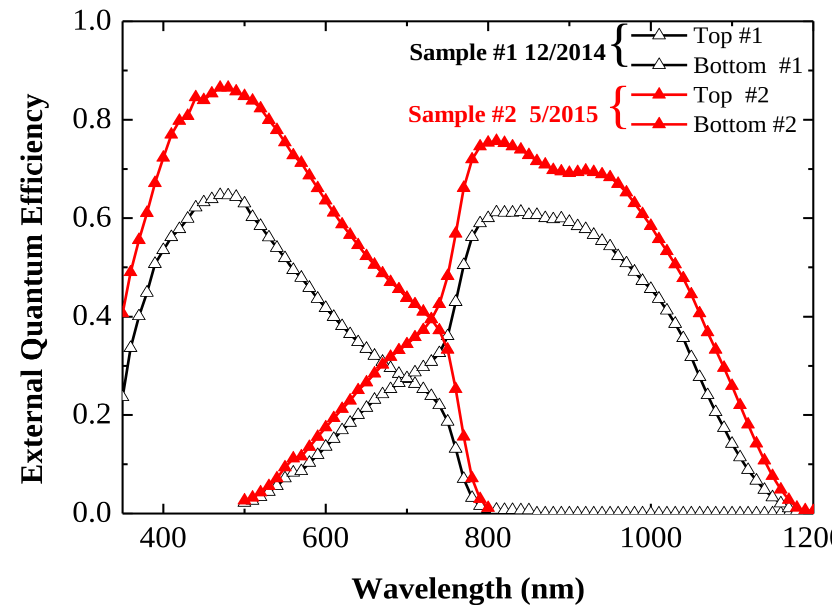
Center for Hybrid and Organic Solar Energy

Schematic cross section of the tandem solar cells under investigation





Experimental J-V characteristics of tandem cells



Experimental External Quantum Efficiency of the tandem cell

Partners

- **Università di Genova** – Dipartimento di Fisica
- **Università del Sannio** - Dipartimento di Ingegneria
- **Università di Napoli "Federico II"–** Dipartimento di Ingegneria dei Materiali e della Produzione
- **Università di Napoli "Federico II"** - Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione
- **Università di Napoli "Federico II"**– Dipartimento di Chimica
- **Università di Modena e Reggio Emilia** - Dipartimento di Chimica
- **Università di Napoli "Federico II"**– Dipartimento di Fisica
- **Università di Trento -** Dipartimento di Ingegneria dei Materiali e Tecnologie Industriali
- **Università "La Sapienza" di Roma -** Dipartimento di Fisica
- **Università "La Sapienza" di Roma -** Dipartimento di Ingegneria Elettrica e delle Tecnologie dell'Informazione
- **Università di Milano Bicocca** - Dipartimento di Scienze dei Materiali