IPVF
INSTITUT PHOTOVOLTAÏQUE D'ILE-DE-FRANCE

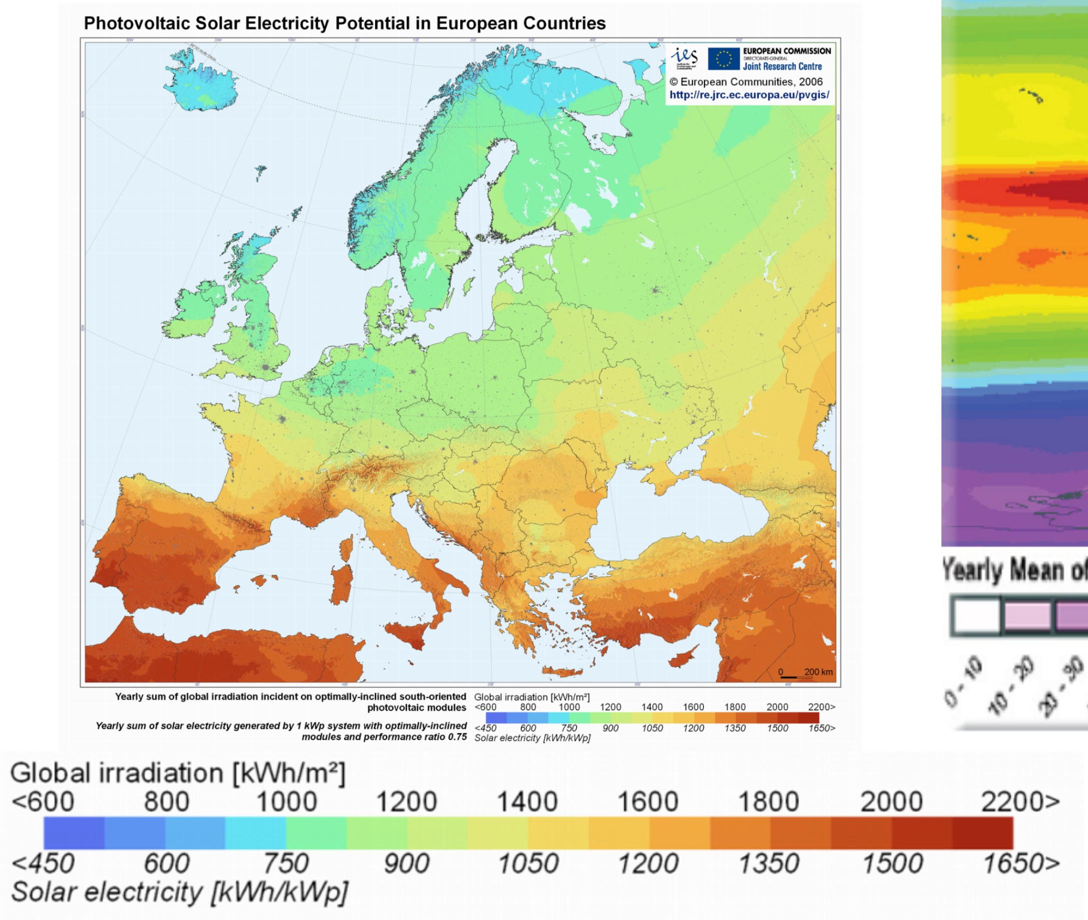
"Photovoltaic research highlights and perspectives at the Institut Photovoltaique d'Ile de France"

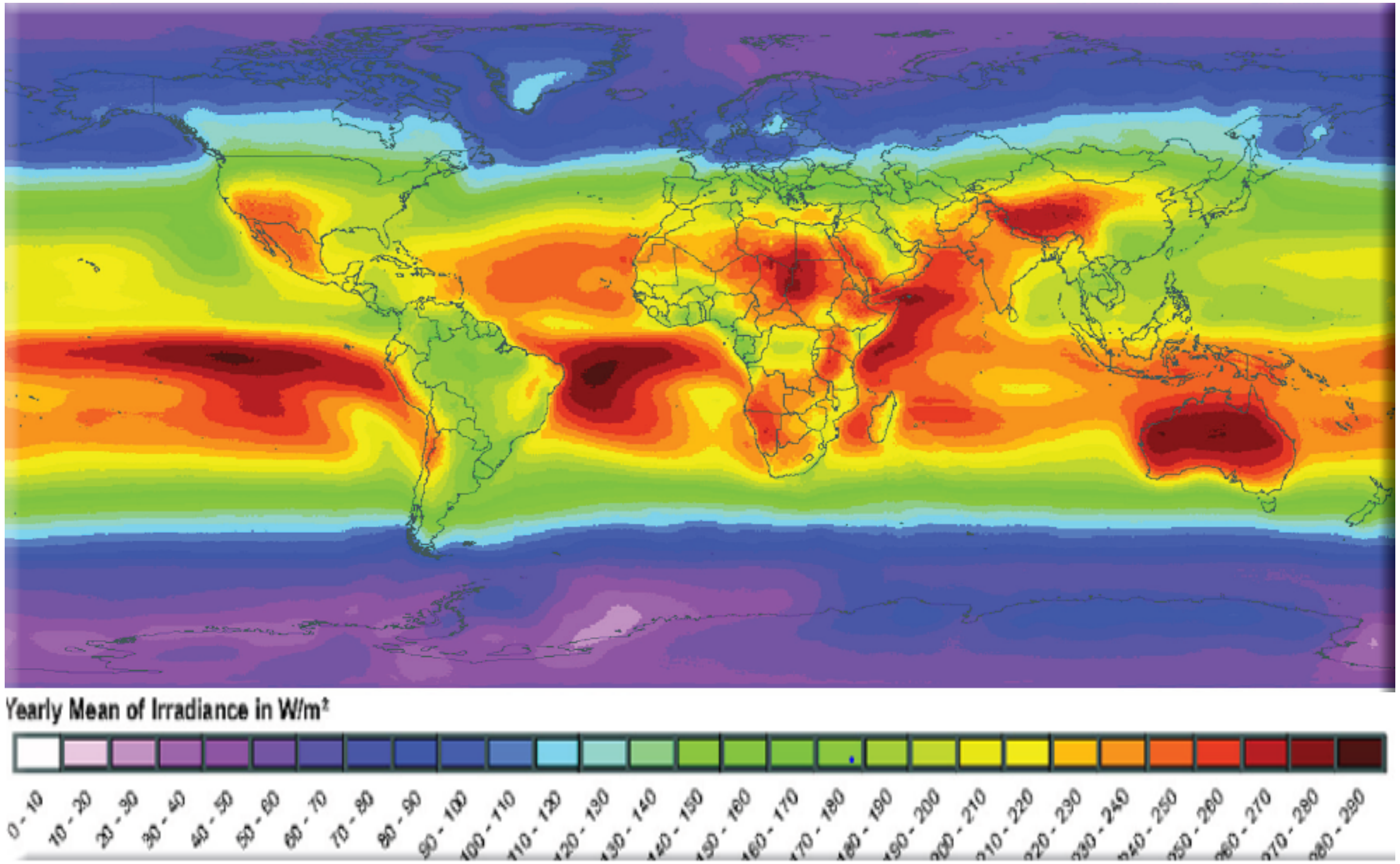
Daniel LINCOT
Scientific Director

1st March 2018, Pontificia Universidad Catolica de Valparaiso

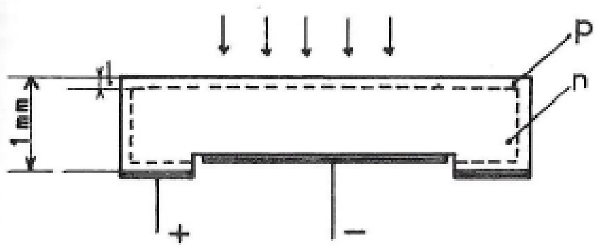
The Solar Ressource

France : 1,3 MWh/m^2/year = 150 L of Oill
540 TWh electricity/year = 500 km^2 solar
5000 km^2 avec PV systems at 10% efficiency

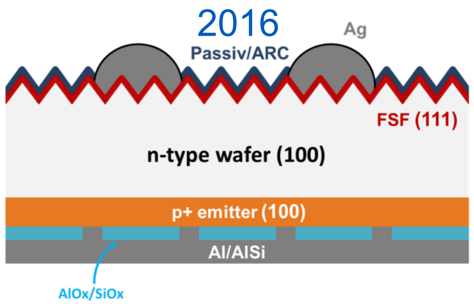


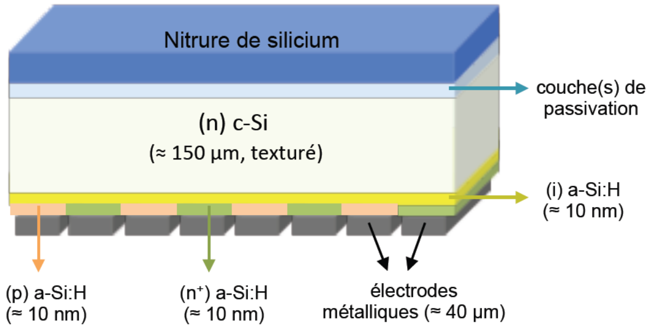


The history of photovoltaics : Silicon Solar Cells

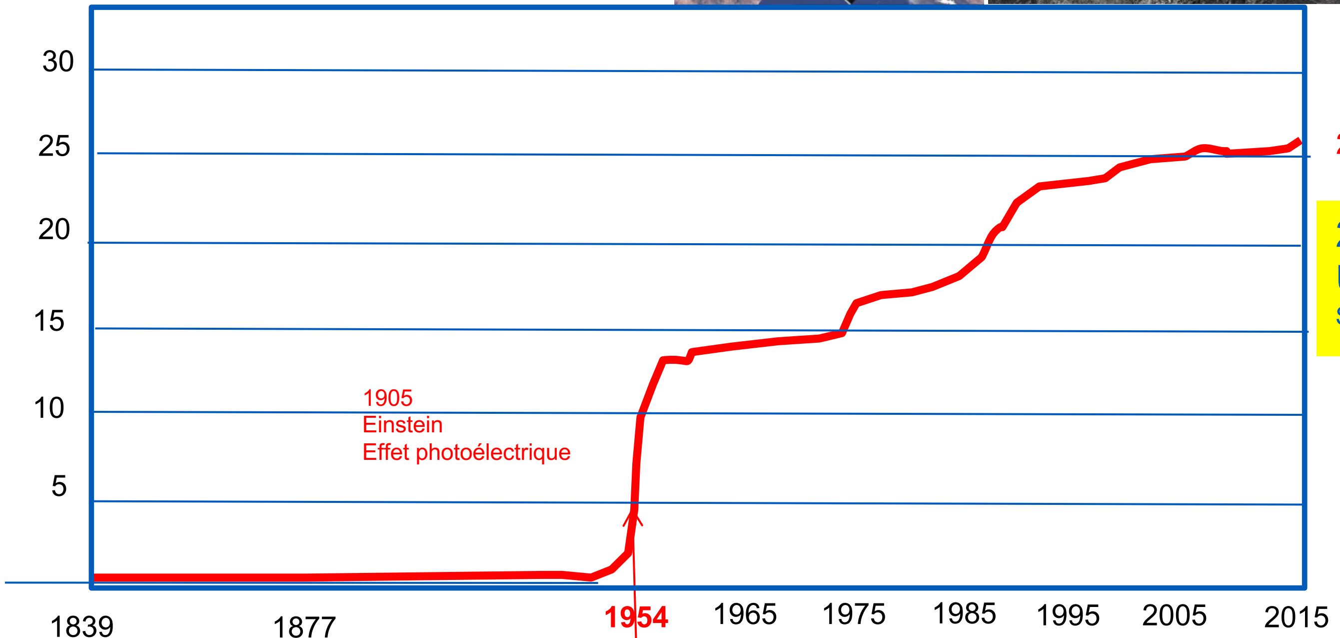


1958 Si cell architecture





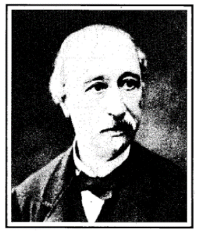
ecord Conversion Efficiency



26,6% (2017)

266 W/m²
Under 1000 W/m²
Solar reference spectrum

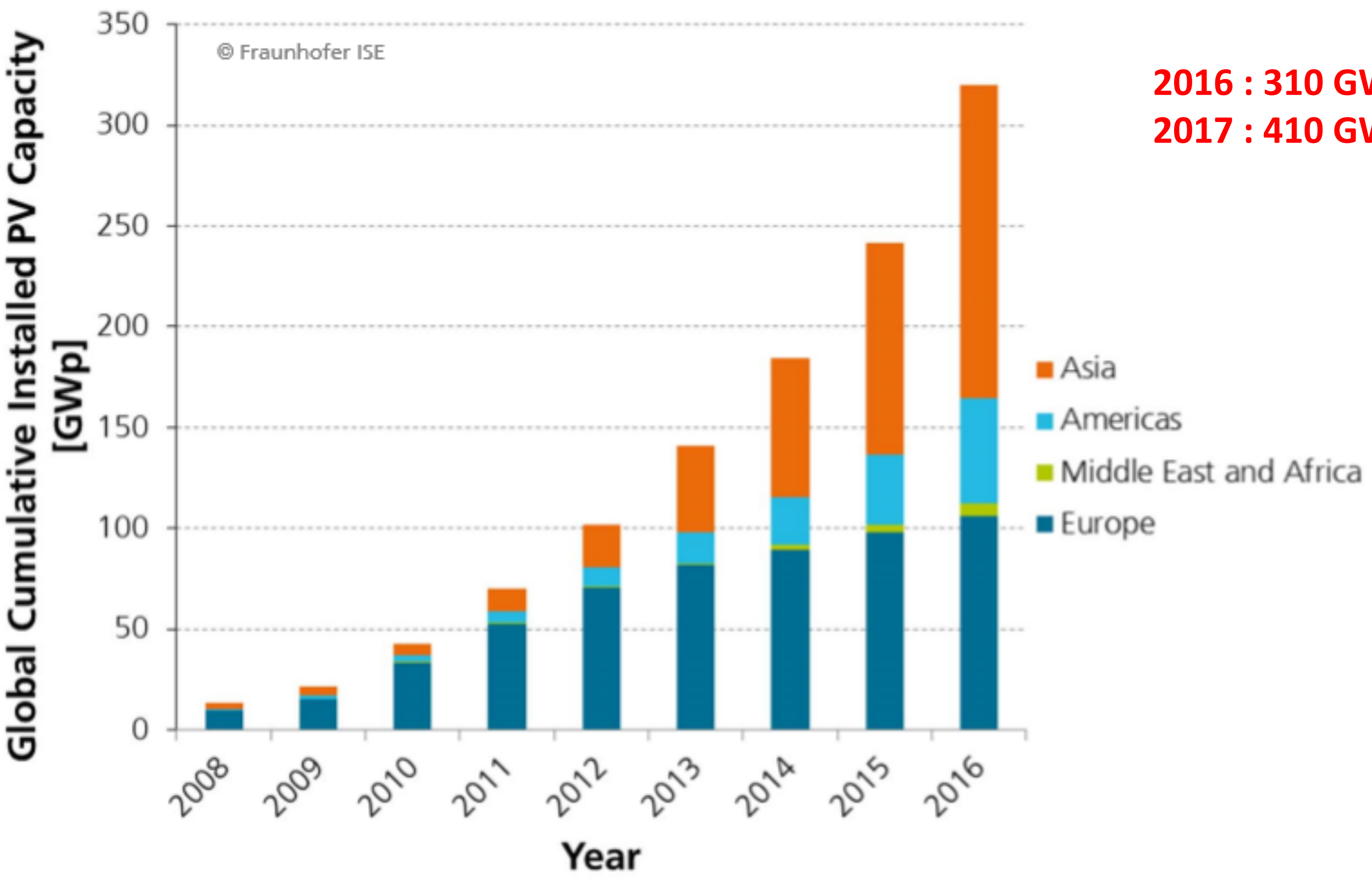
EDMOND BECQUEREL
The Discoverer of Photovoltaics



1877
W.G. Adams
& R.E. Day
Cellules
Se 1%

Chapin &Fuller
&Person
Si(6%)

Global Cumulated Capacity of Installed Photovoltaics

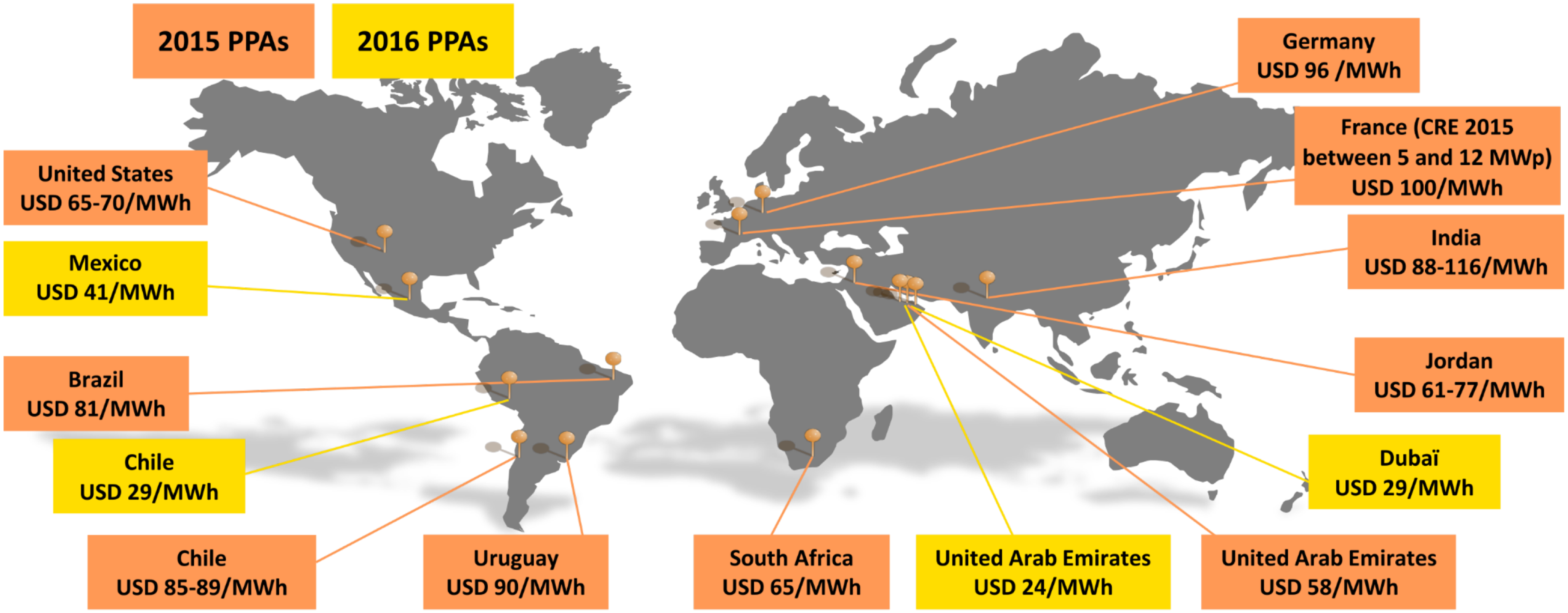


2016 : 310 GW (75 GW in 2016 with 35 in China)
2017 : 410 GW (100 GW in 2017 with 58,2 in China)

500 GW in 2020
4.4 TW of PV in 2050 (IEA 2015)

PV Competitiveness in the energy market

Recent announced long-term contract prices for new solar electricity



This map is without prejudice to the status or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area

Adapted from IEA Renewable Energy Medium Term Market Report 2015

France 2016 : 63 Euros/MWh

PV Penetration in National Markets

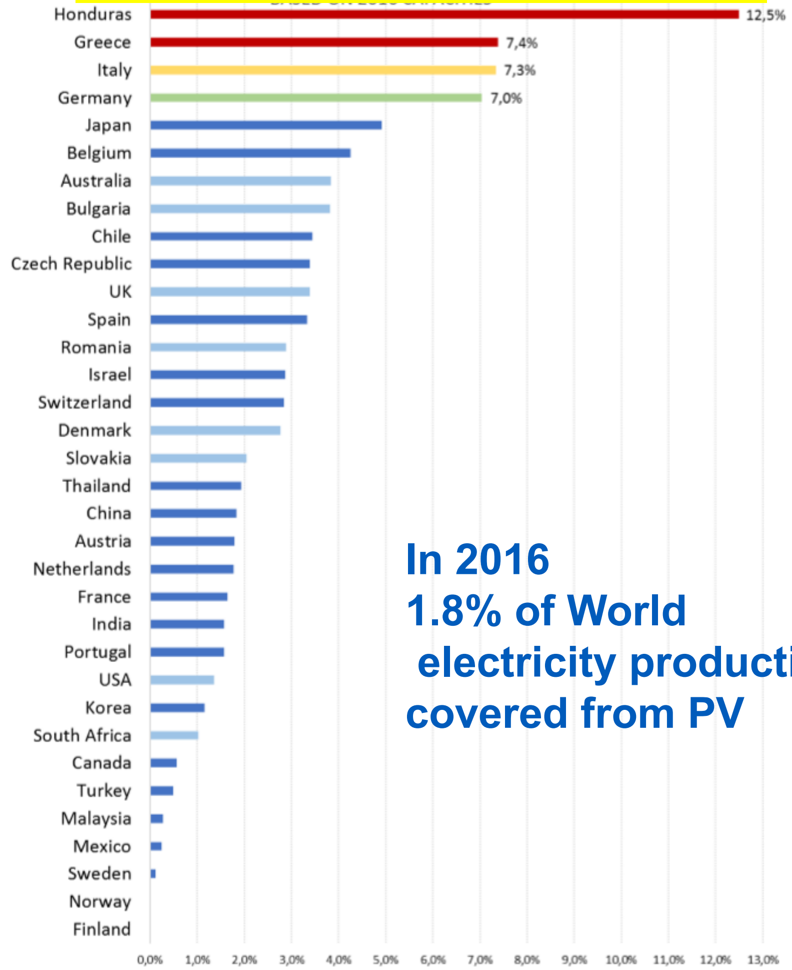
TABLE 1: TOP 10 COUNTRIES FOR INSTALLATIONS AND TOTAL INSTALLED CAPACITY IN 2016

TOP 10 COUNTRIES IN 2016 FOR ANNUAL INSTALLED CAPACITY			TOP 10 COUNTRIES IN 2016 FOR CUMULATIVE INSTALLED CAPACITY		
1	China	34,5 GW	1	China	78,1 GW
2	USA	14,7 GW	2	Japan	42,8 GW
3	Japan	8,6 GW	3	Germany	41,2 GW
4	India	4 GW	4	USA	40,3 GW
5	UK	2 GW	5	Italy	19,3 GW
6	Germany	1,5 GW	6	UK	11,6 GW
7	Korea	0,9 GW	7	India	9 GW
8	Australia	0,8 GW	8	France	7,1 GW
9	Philippines	0,8 GW	9	Australia	5,9 GW
10	Chile	0,7 GW	10	Spain	5,5 GW

Snapshot of Global Photovoltaic Markets - IEA PVPS 10

13 : France 559 MW

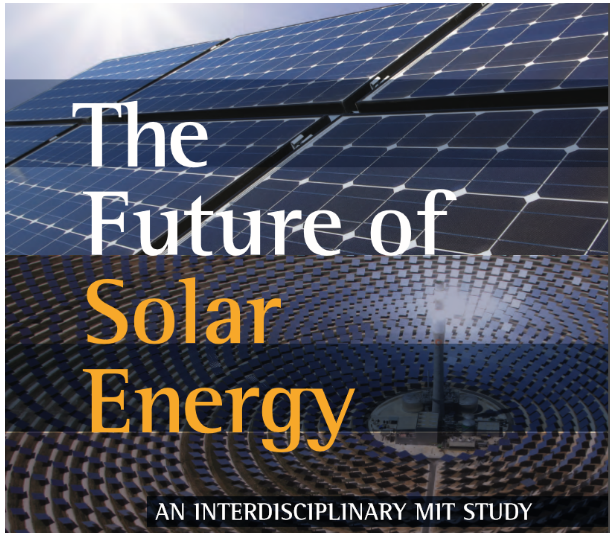
National PV penetration
in 2016 based on capacity (IEA PVPS)

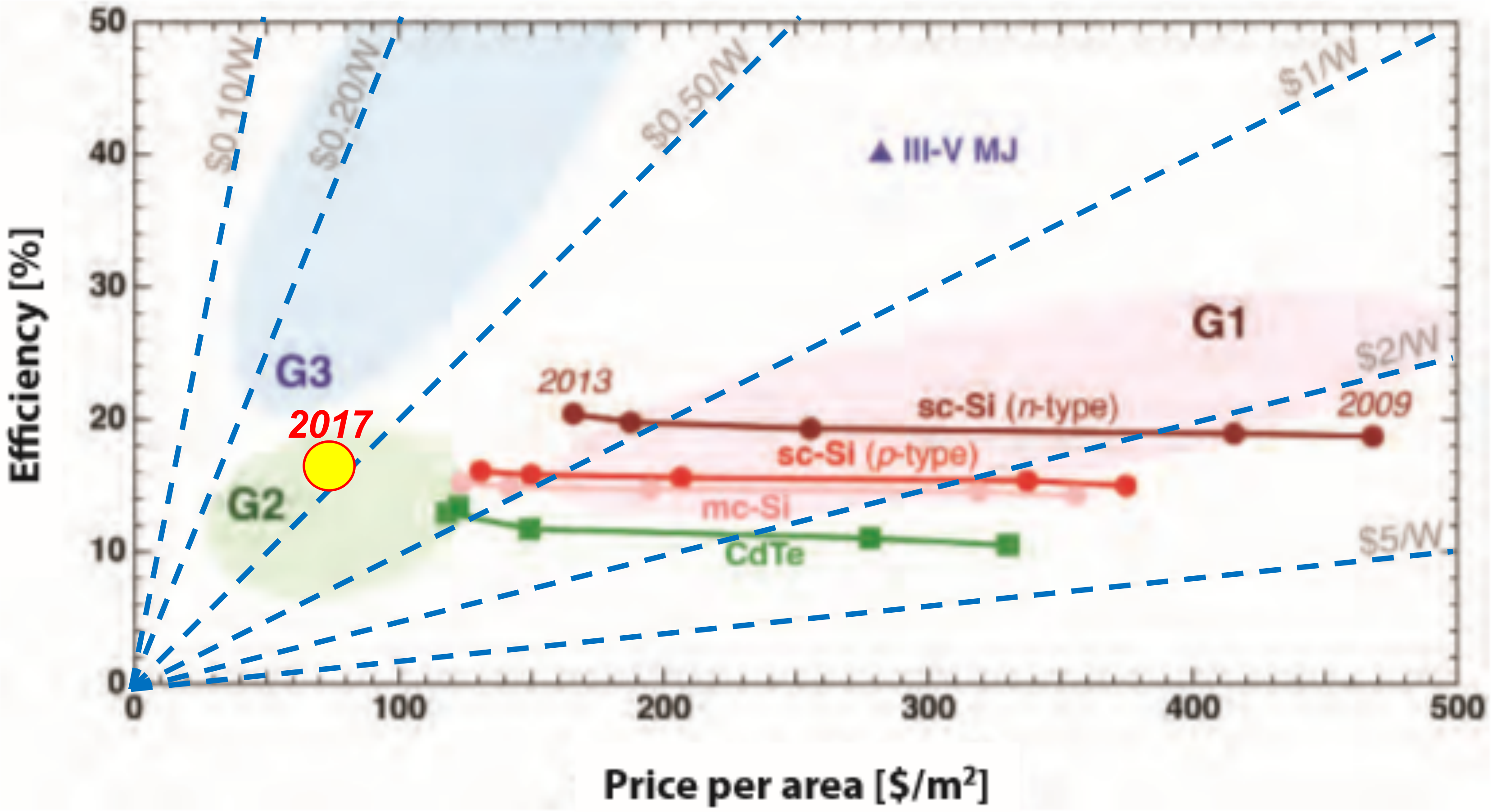


In 2016
1.8% of World electricity production covered from PV

The unexpected Performance/Cost Scenario

2015





What role of R&D in the next period ?

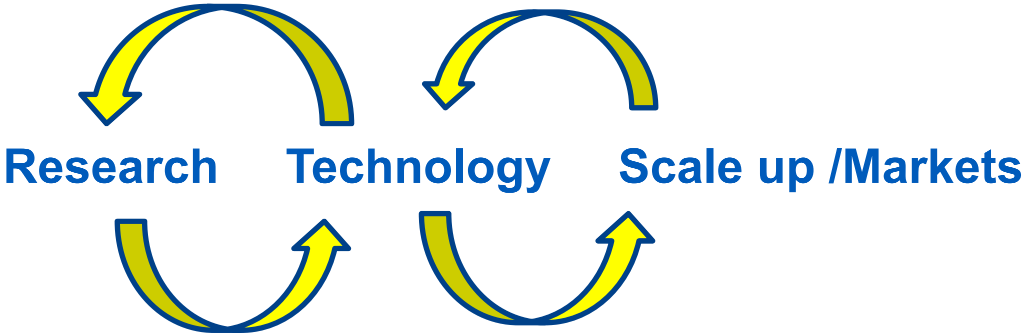
The key of Success : *Efficiency → fiability → costs*

Remote applications (niche markets) : High costs OK

Efficiency Challenge
Fiability Challenge
Cost Challenge
Time Challenge

Environnemental Challenge
Systems Challenge

Large scale terrestrial application : competitive costs of pV electricity mandatory

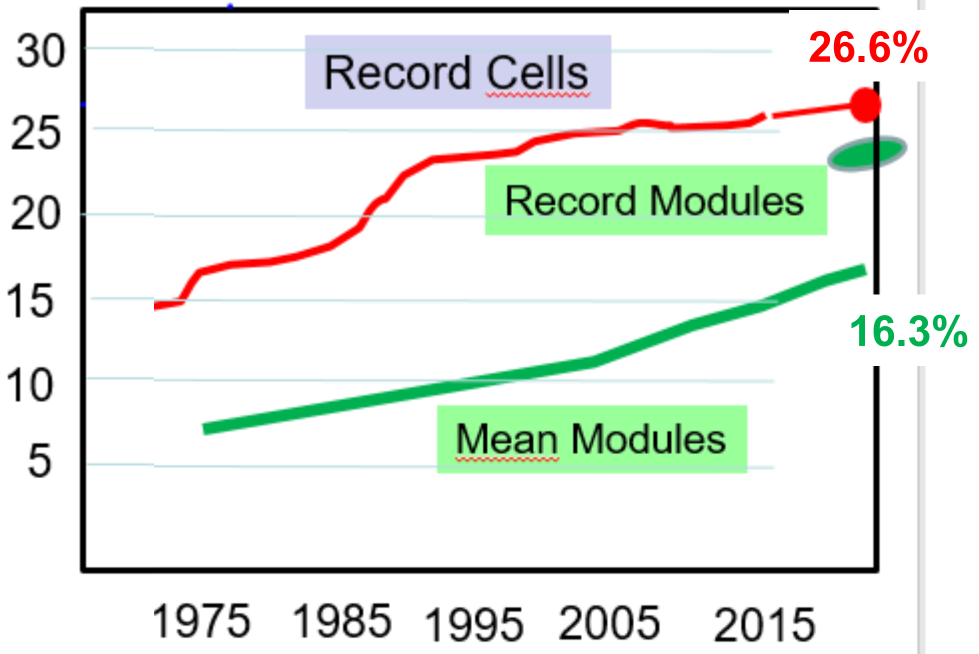


Industrial Tranfer of Record Efficiencies

Example : Sun Power (Total)

Industrial Cells at 25.2% (2015)

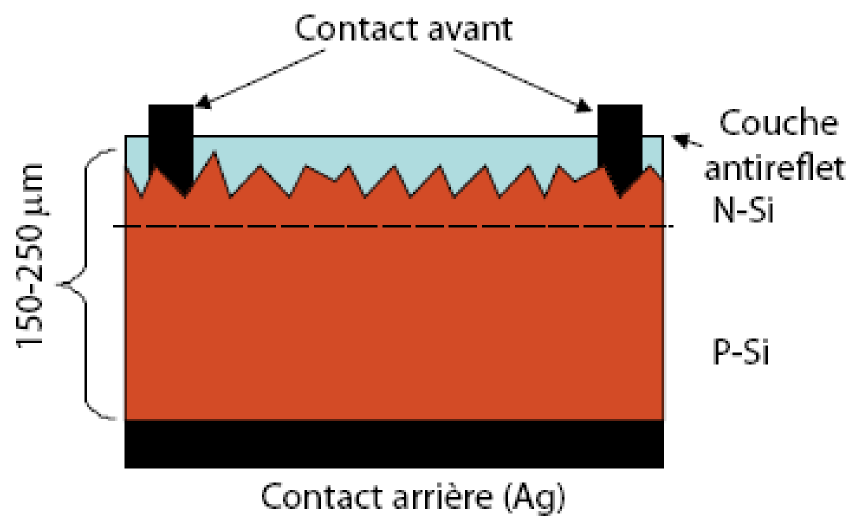
Record Modules at 24.1 % (2016)



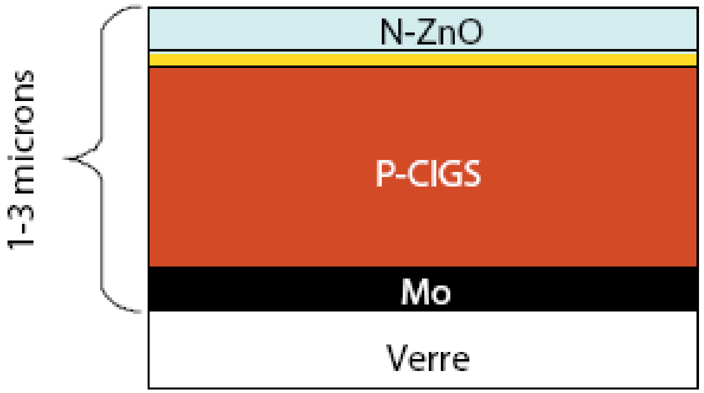
Absolute record

29,1 %

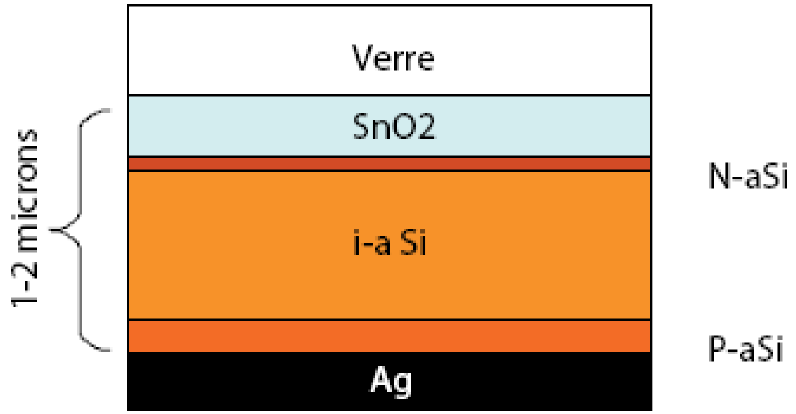
Cellule au silicium cristallin



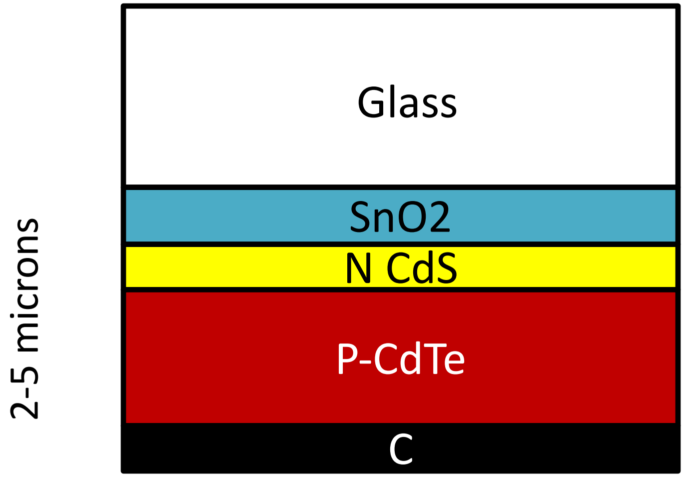
Cellule au Cu(In,Ga)Se_2



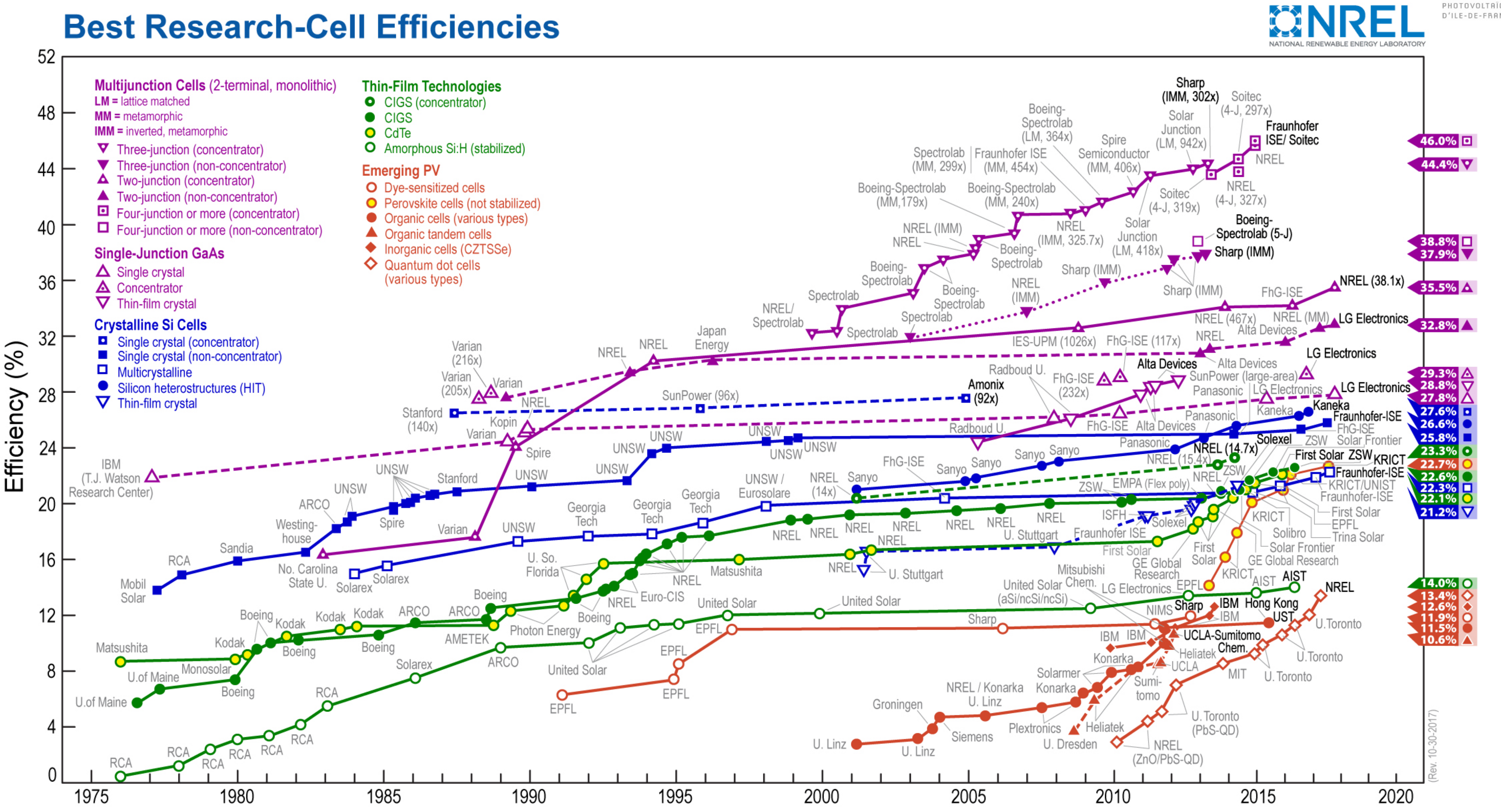
Cellule au Silicium amorphe



Cadmium telluride solar cell



The research front of PV efficiency & technology competition

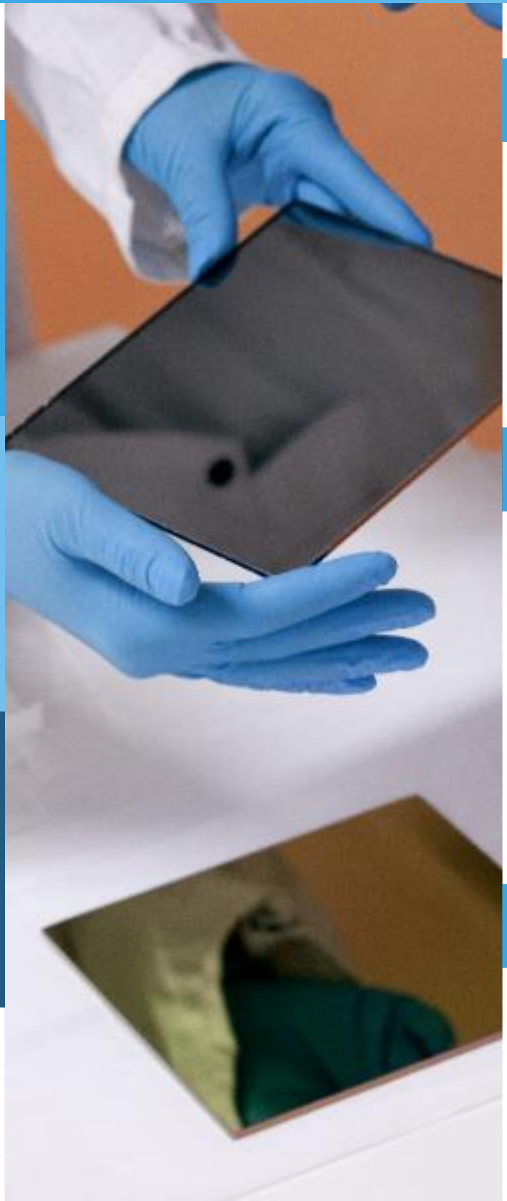


IPVF in Brief

€66
MILLION
6 YEARS R&D BUDGET

150
INVOLVED RESEARCHERS

8,000
M^2 BUILDING



Ambition

Perform upstream research with a strong industrial foothold and operate a world-class experimental platform to:

- Radically improve the performances of PV cells,
- Give birth to disruptive PV-based technologies.

Founding Members

EDF, TOTAL, CNRS, X (École polytechnique), Air Liquide (creative oxygen), HORIBA, RIBER

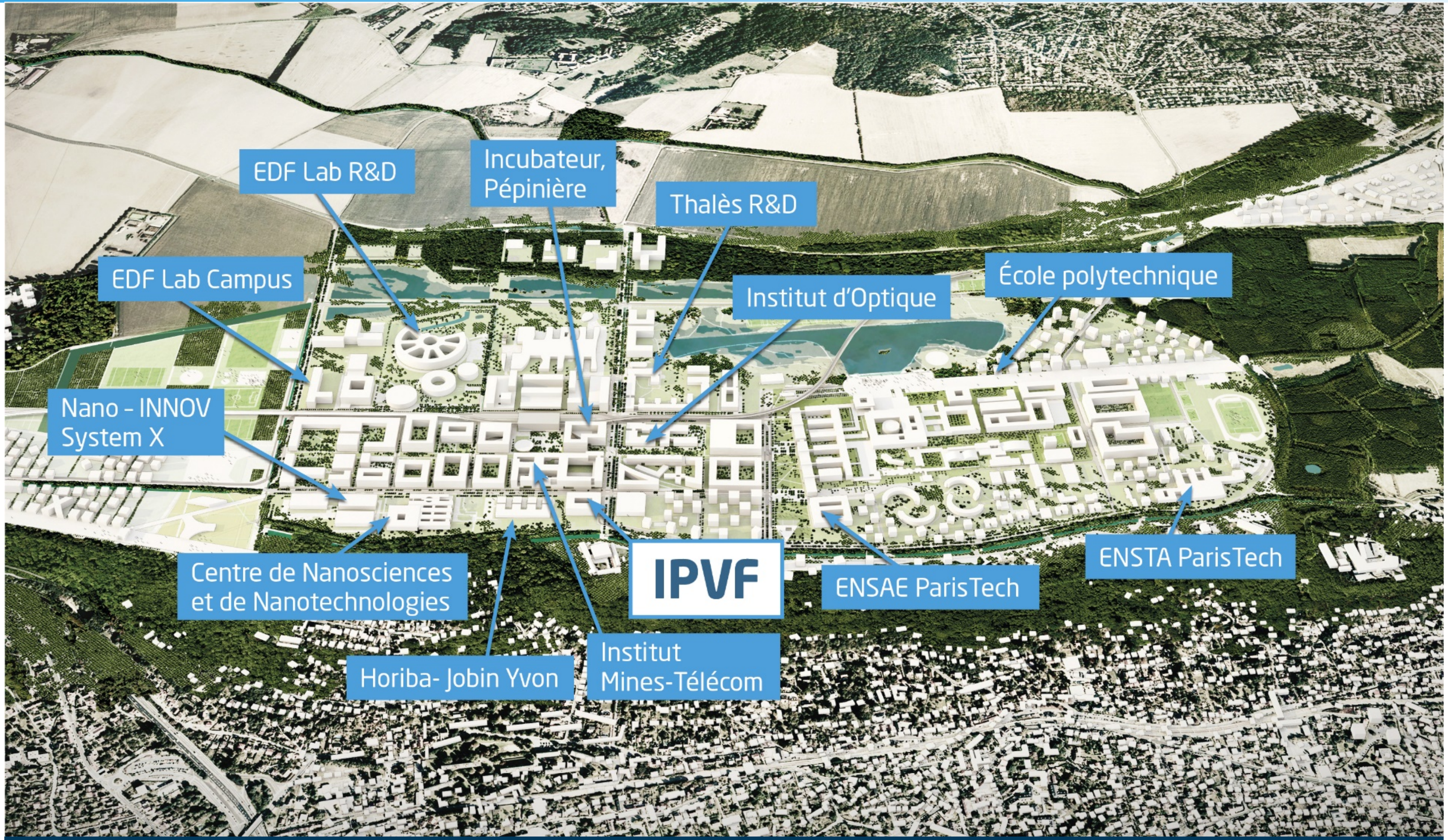
An Institute for Energy Transition

Investissements d'Avenir, ANR

Key Dates

Oct. 29, 2013	Signing of the agreement with the ANR (French Agency for Research)
Avril 28, 2014	Launch of SAS IPVF
Oct. 2014	Launch of joint research program
Nov. 2014	Launch of building program
Q1 2015	Purchase of the first IPVF equipments
Q1 2015	Recruitment of the first IPVF researchers
S2 2017	Opening of the IPVF building

The Platform from 2017 on



New dedicated building at the heart of the Paris-Saclay campus

IPVF resources

Scientists

150 researchers involved

- 100 hosted in the new building in Paris-Saclay
- ~25 directly hired by IPVF

Free space ready to welcome guests scientists & start-ups

R&D facilities

> 70 state-of-the art tools, owned and operated by IPVF

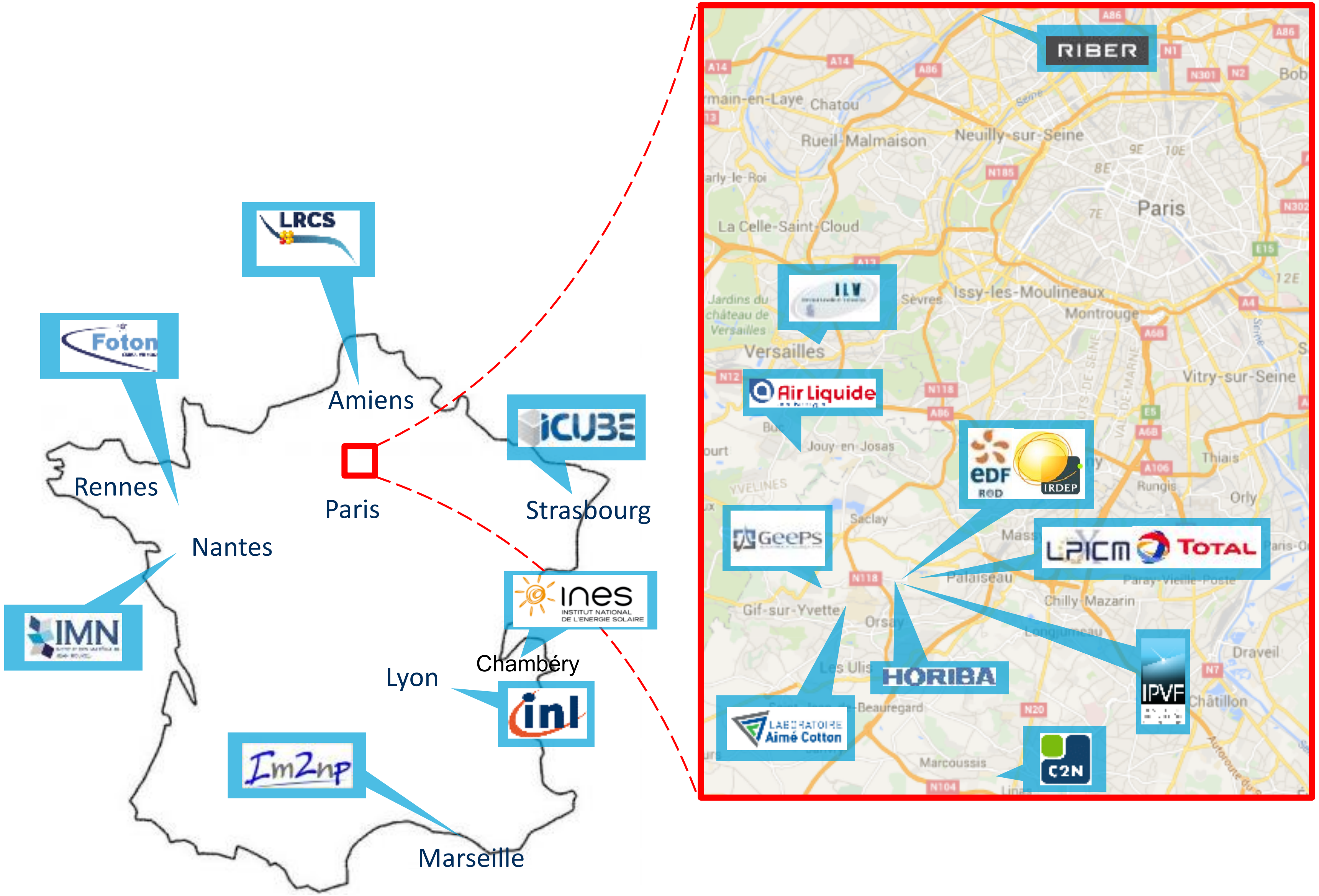
- Analytical
- Material & Device Process

Up-time available for contract research

12 Partner Academic Laboratories

LPICM	P. Roca i Cabarrocas, E. Johnson, Y. Bonnassieux	C2N	S. Collin, J.C. Harmand	inl	M. Lemiti
IRDEP	D. Lincot, J.F. Guillemoles, N. Naghavi	ILV	A. Etcheberry, M. Bouttemy	Foton	O. Durand, J. Even
GeePs	J.P Kleider, Ch. Longeaud, D. Mencaraglia	iCUBE	A. Slaoui, T. Fix	IMN	A. Lafond, N. Barreau
LRCS	F. Sauvage	Im2np	L. Escoubas, J. Le Rouzo	Laboratoire Aimé Cotton	E. Deleporte

Involved French Laboratories Network



IPVF organigram

Board
5 industrial members
2 academic members

Scientific Advisory Council
International Experts

Jean-François Minster
Chairman

Bruno Carlotti
Managing Director

Sonia Haouka
Executive Assistant

Daniel Lincot
Scientific Director

Denis Jahan
Partnership Director

Bernard Drévillon
Education Director

Joint CNRS IPVF Lab
Jean François Guillemoles
Director

Scientific Committee

Partnership Committee

Education Committee

Christophe Bonelli
Laboratories Manager

Olivier Roussel
ESH & Facility Manager

Bérengère Larue
Financing Manager

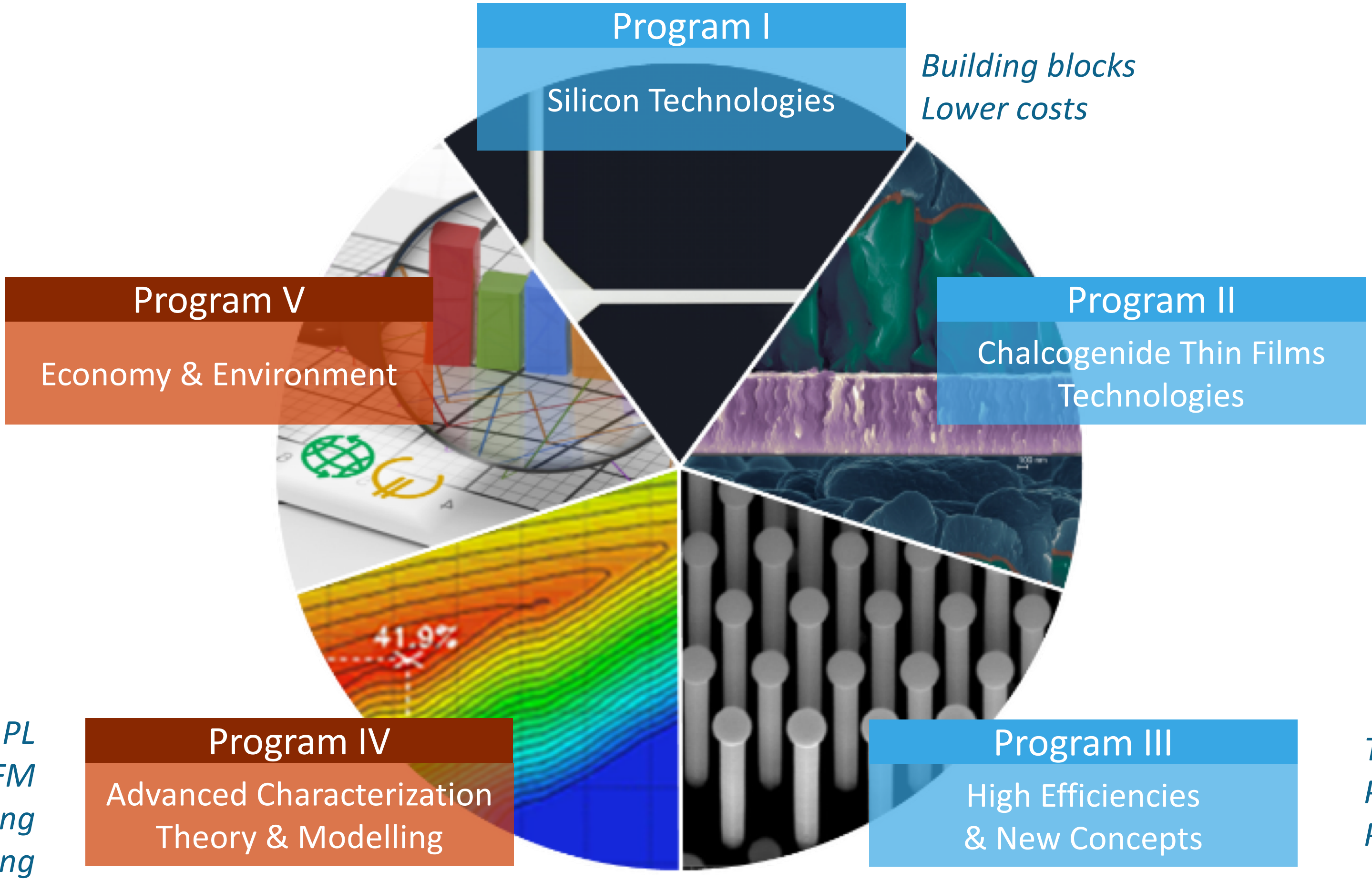
Researchers

Training

- Renewable Energy Science & Technology Master’s Degree
- Doctoral and post-doctoral training
- Massive Open Online Courses (MOOC)

master renewable energy
Science & Technology Excellence

Scientific Program of IPVF



Building blocks
Lower costs

Light weight and flexible cells
Wide bandgap

Tandem cells
Perovskite & III/V cells
Photonics

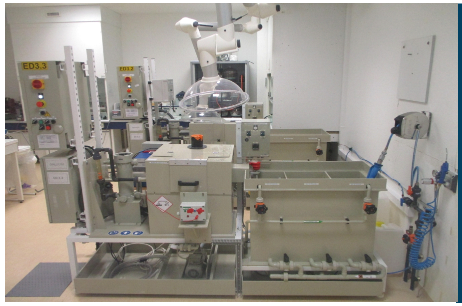
TR-FLIM, Hyperspectral PL
AFM, CP-AFM
XPS & GD-OES coupling
Ab-initio and device modelling

Market assessment
Cost calculation

Materials and Devices Processing

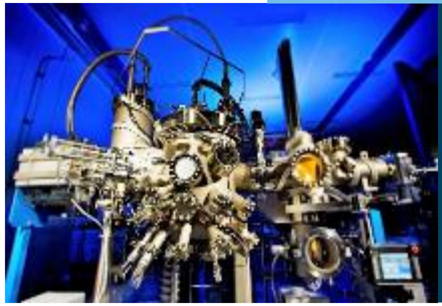
IPVF invested massively in a set of more than 70 tools allowing to synthetize all the materials needed for opto-electronic devices.

Solution Deposition



- Electrodeposition
- Chemical deposition
- Spin Coating
- Slot Die Coating

PVD



- III-V & SiGe Epitaxy (MBE)
- CIGS Co-evaporation
- TCO & metals Sputtering
- Perovskites & Metals evaporation

Heat Treatment

- B & P diffusion
- Firing
- Annealing
- Metal Induced Crystallization

Etching / Cleaning

- RF or Tailored voltage waveform (TVW) Reactive Ion Etching(RIE)
- Laser ablation
- Wet benches

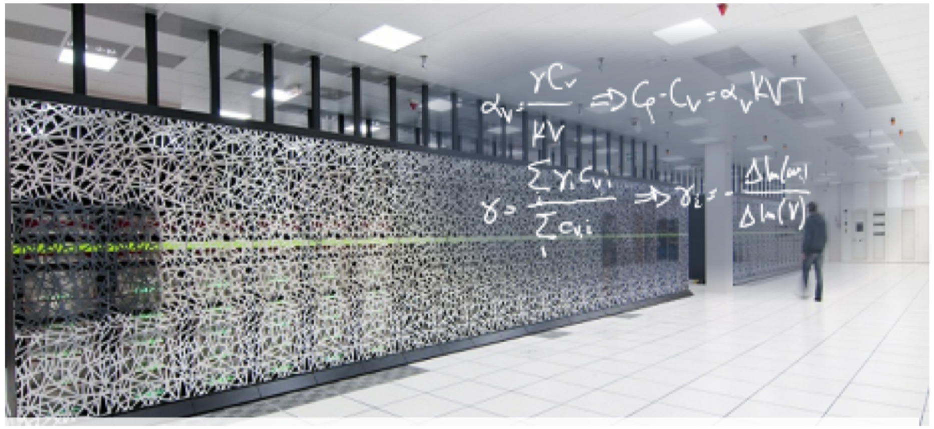
CVD

- TCO & Buffer layers ALD
- Oxydes & Nitrides PE-ALD
- SiOxCyNz PECVD
- C-Si low T° epitaxy (PECVD)

Our key partners labs for Material Processing:

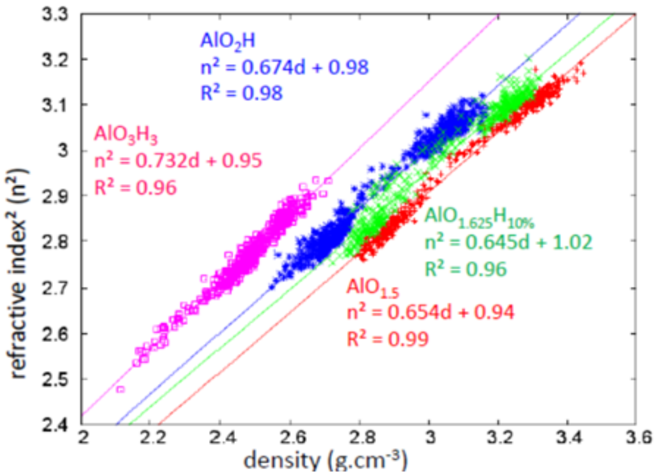
LPICM, C2N, Air Liquide, RIBER

Theory and Modeling

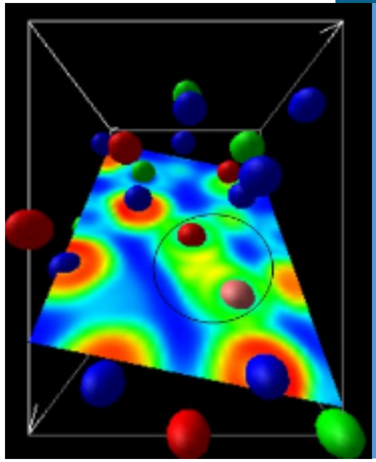


Envision and explore new materials and novel device architectures with our modeling teams.

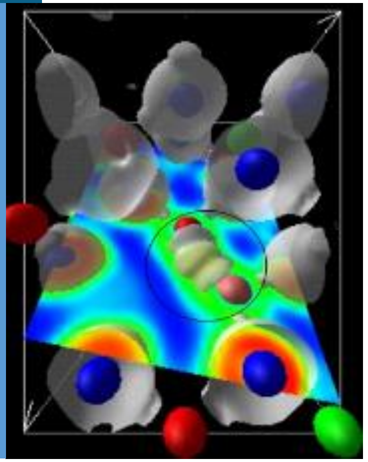
They developed tools and methodologies to assess disruptive technologies that will be used in next generation devices.



Material Modeling

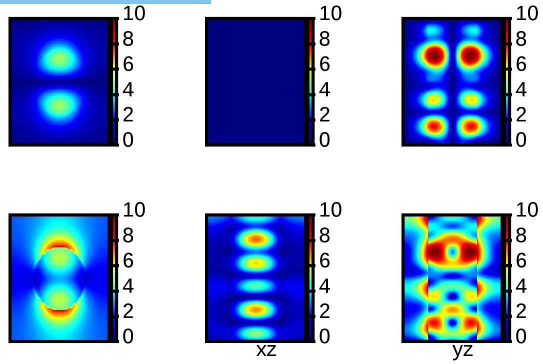


- Ab initio calculations (DFT, Hybrid functional, AIMD,GW…)
- Process modeling



Devices Modeling

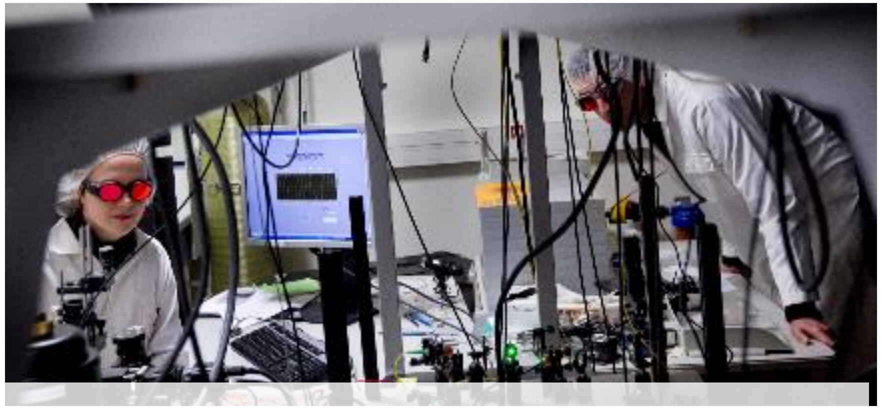
- Solar cells modeling (Sentaurus, Silvaco, Scaps …)
- Optical modeling (RCWA,FDTD…)
- Coupling of advanced electrical & optical modeling



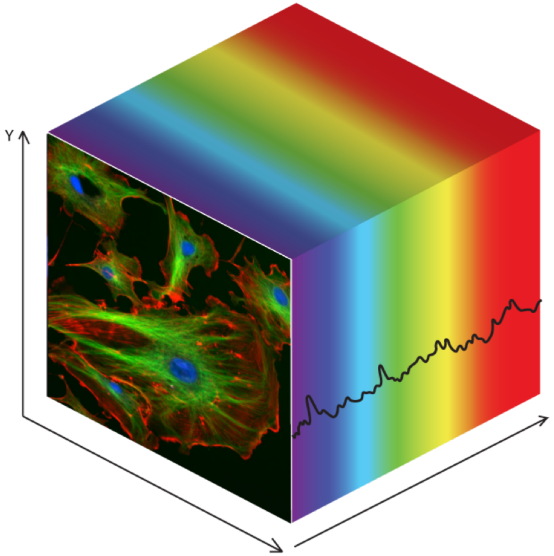
Our key partners labs for Modeling:

GeePs LPICM C2N IRDEP

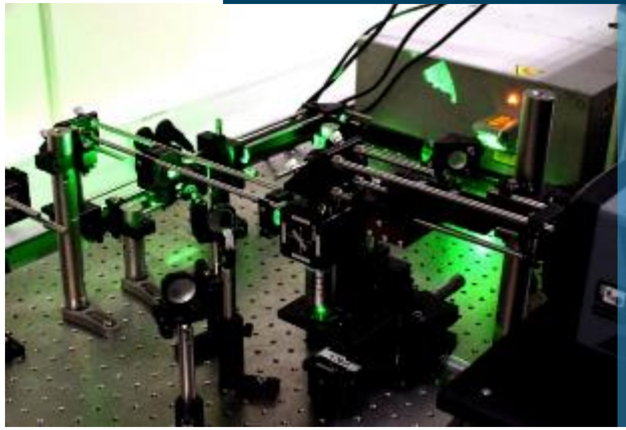
Characterization of materials and device properties



Characterization is key to deeply understand and optimize solar cells. Therefore IPVF develops strong skills in this field and set up an advanced and differentiating platform covering electro-optical, chemical and structural characterizations.



Electro-Optical Characterization



- µ PCD (Microwave PhotoConductance Decay)
- SPM Technologies (AFM, KPFM, Resiscope,EFM,STM…) on irradiated and/or biased samples
- FTPS (Fourier Transform Photocurrent Spectroscopy)
- TRPL / TRFLIM (Time Resolved Photoluminescence / Time Resolved Fluorescence Lifetime Imaging)
- Photoreflectance
- In-Situ Photoluminescence
- Standard Solar Cells Characterization (Solar simulators, IQE, Light Soaking,…)

Chemical & Structural Characterization

- X-ray Photoelectron Spectroscopy (XPS) and Glow Discharge Optical Emission Spectroscopy (GD-OES) coupled analysis
- X-Ray Diffraction (XRD)
- Raman spectroscopy
- Scanning Electron Microscopy (SEM- EDS)

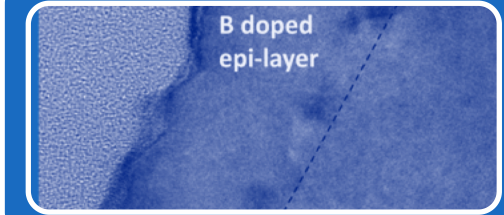
Our key partners labs for Material & Devices Characterizations:

GeePs LPICM ILV IRDEP

The full picture of IPVF scientific projects : The « Alphabet » of IPVF

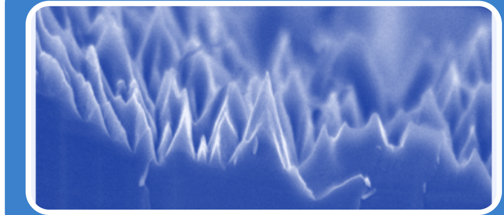
- ***Silicon solar cells***
  - **A : High efficiency silicon solar cells**
- ***Thin film chalcogenide solar cells***
  - B: **CIGS solar cells on flexible substrates**
  - C: Wide gap CIGS solar cells
- ***New concepts***
  - D: New concepts for ultrahigh efficiencies
  - E : High efficiency III-V solar cells
  - F: Hybrid perovskite solar cells
  - T: **Tandem solar cells and modules**
- ***Advanced characterization and modeling***
  - G: Nanopositioning methods
  - H: Electrical and optoelectronic characterization
  - I: Advanced chemical characterization
  - J: Theory and Modelling
  - M: (MOPGA) Characterization of complex interfaces
- ***Economical, social and environmental aspects***
  - K: Economics and environment

Project A : IPVF High efficiency c-Si in a nutshell



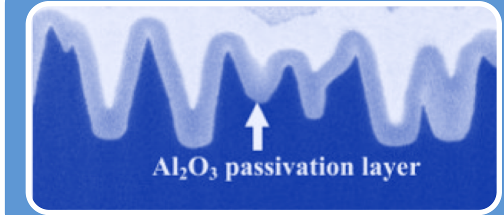
Low temperature epitaxy

- Boron and Phosphorus-doped low temperature epitaxy (<400 °C) by PECVD
- **Hybrid (epi/diffusion) or full epitaxial tunnel junction for 2T tandem**



Light Management

- Nanotexturation using RIE with Tailored Voltage Waveform excitation
- **IR management for tandem solar cells**



Passivation layers

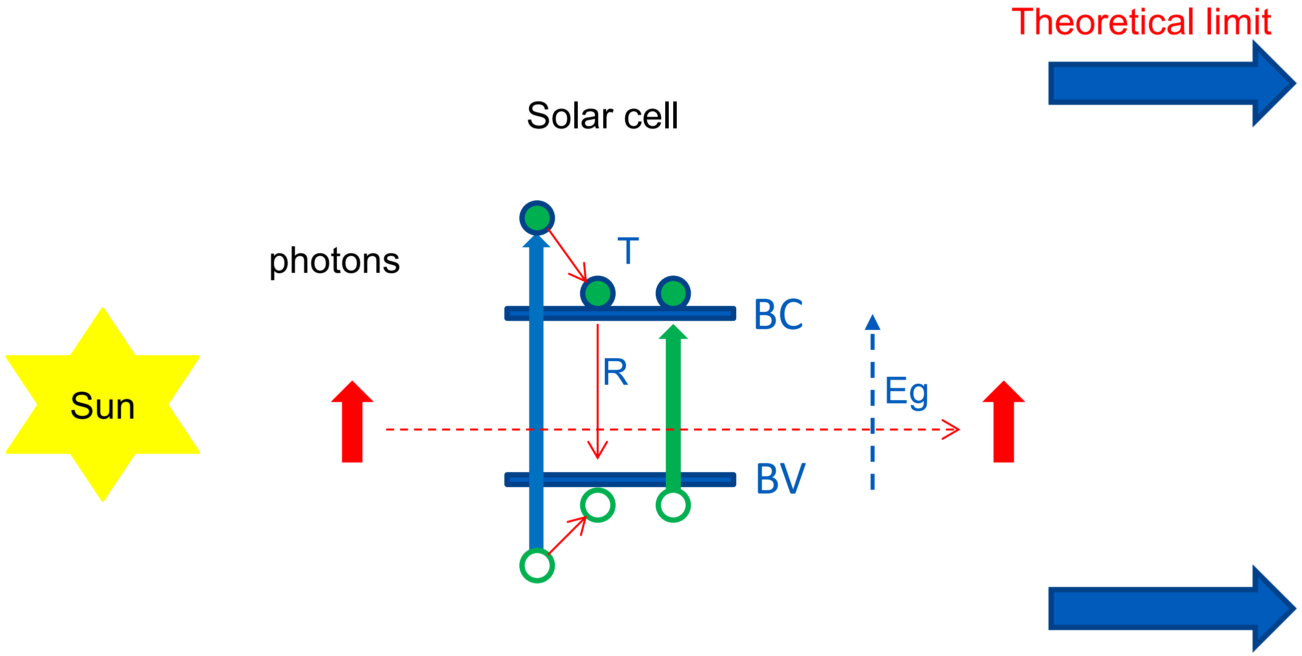
- Standard c-Si passivation materials (Thermal SiO_2, PECVD Si based materials… + ALD Al_2O_3)
- **New passivating contacts materials mostly Transition Metal Oxides**

Metallization and Interconnexions

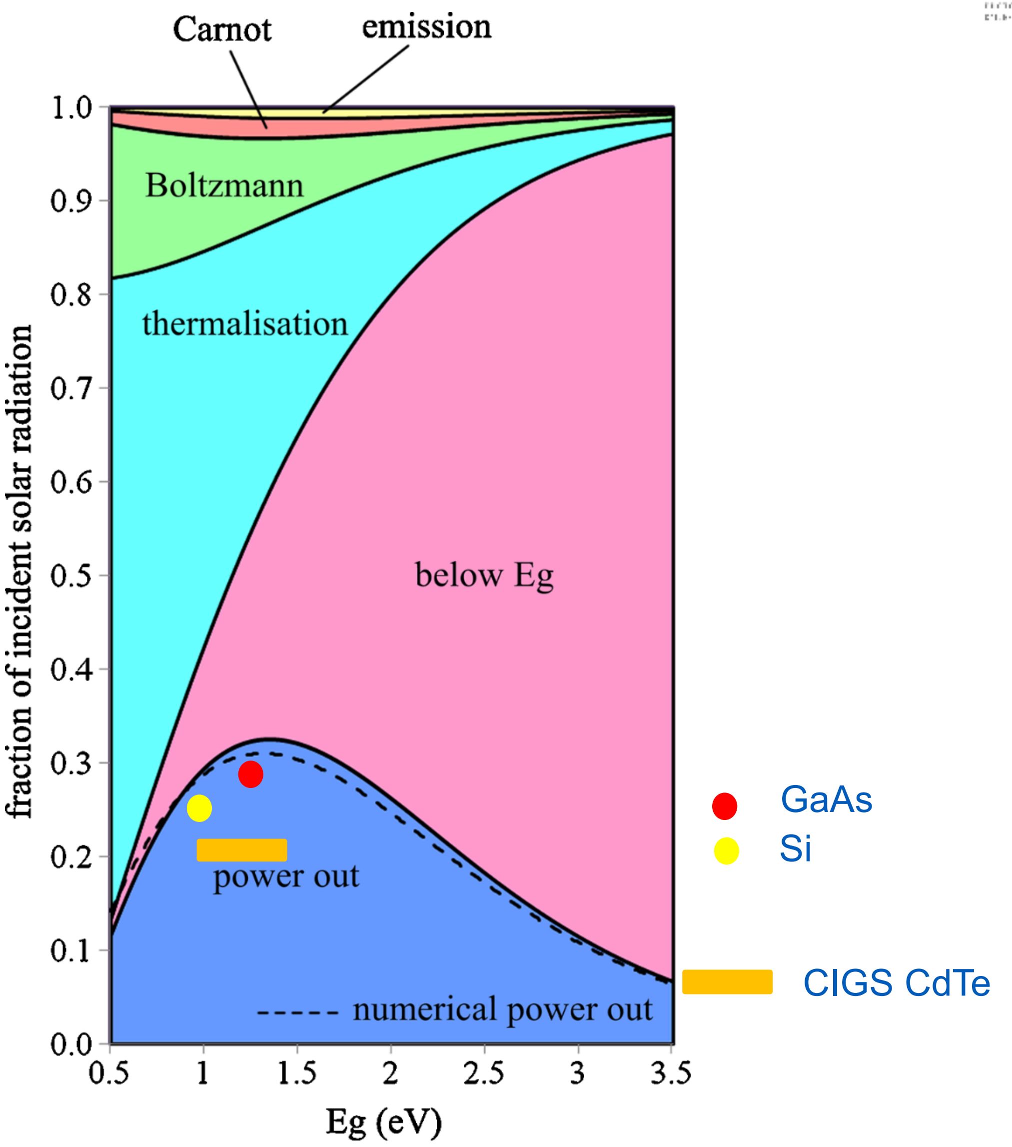
- Bifacial plating for PERT cells **and tandem**
- **Interconnection schemes for PERC/PERT and tandem**

Theoretical Limit of Photovoltaic Conversion efficiency

L.C. Hirst et al. – Progress in Photovoltaics – 2011; 19:286-293



The conversion efficiency limit
For a single junction
Schockley Queisser (33%)



T : Energy Losses by Thermalization
R : Energy Losses by Recombination

What Role of R&D at IPVF

Efficiency Challenge
Cost Challenge
Time Challenge

The « 30Cube » roadmap

The Thirty Cube R&D Roadmap : 30-30-30 for modules

http://www.ipvf.fr/en/the-303030-initiative-for-the-modules/

Module efficiency

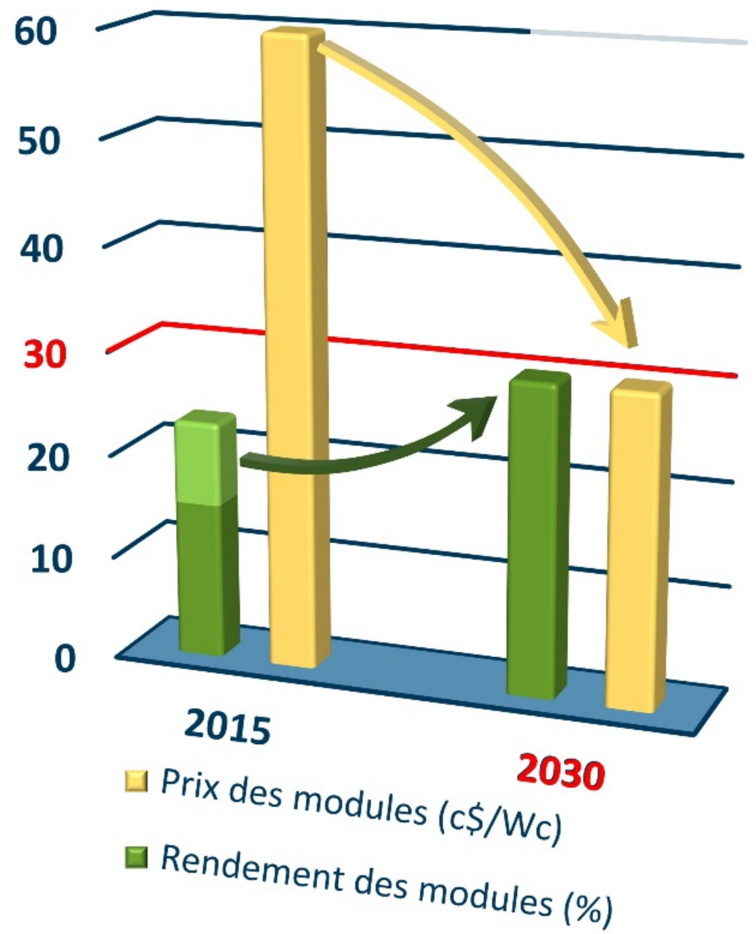
> 30%

At a price of

< 30 c$/Wc

for

2030



An international R&D initiative

PARIS2015
CONFÉRENCE DES NATIONS UNIES SUR LES CHANGEMENTS CLIMATIQUES
COP21·CMP11

Jean-François MINSTER
IPVF

Philippe MALBRANCHE
INES

Andreas BETT
Fraunhofer ISE

Michael GRAETZEL
EPFL

Yoshita OKADA
RCAST, NextPV

Jean-François GUILLEMOLES
CNRS, NextPV

Marika EDOFF
Uppsala University

Alex FREUNDLICH
University of Houston

Christophe BALLIF
EPFL

Michael POWALLA
ZSW

Agreed by e-mail

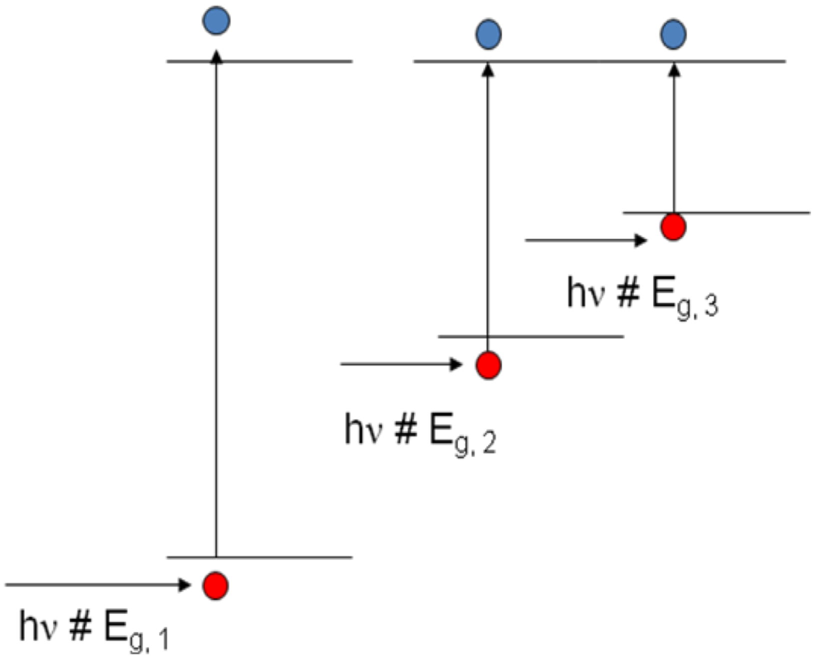
Jeff POORTMANS
IMEC

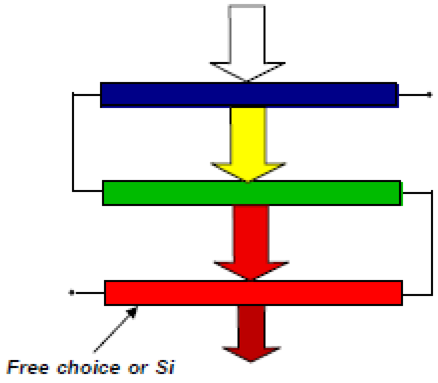
Wim C. SINKE
ECN

Ayodha N. TIWARI
EMPA, EPFL

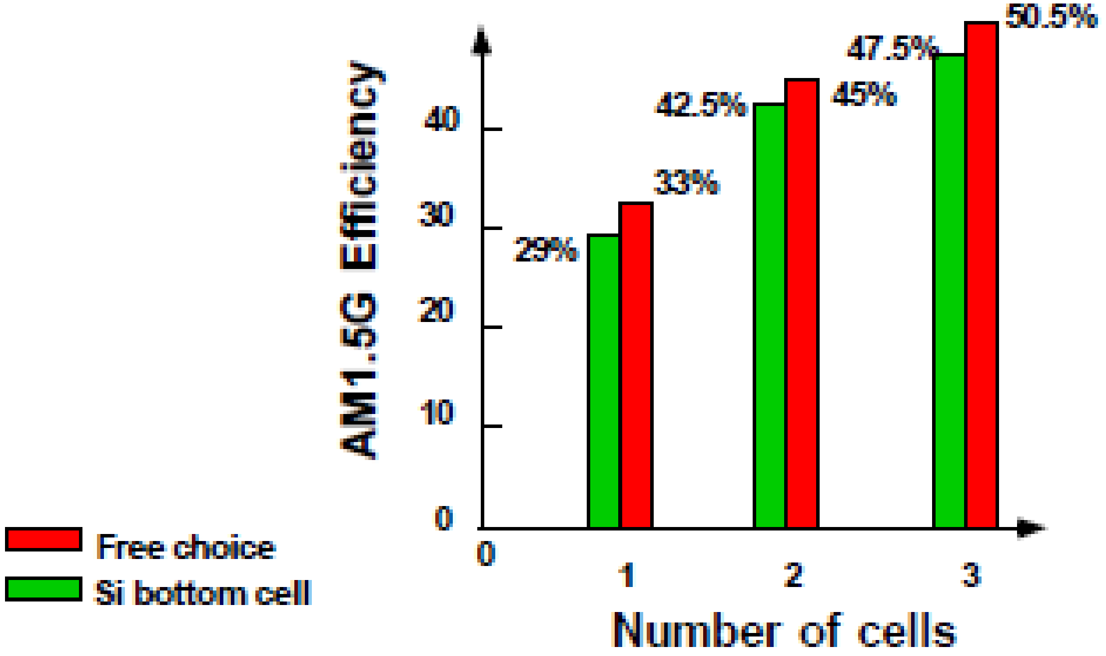
Martin GREEN
UNSW

A priority program : Multijunctions





From : M. Green

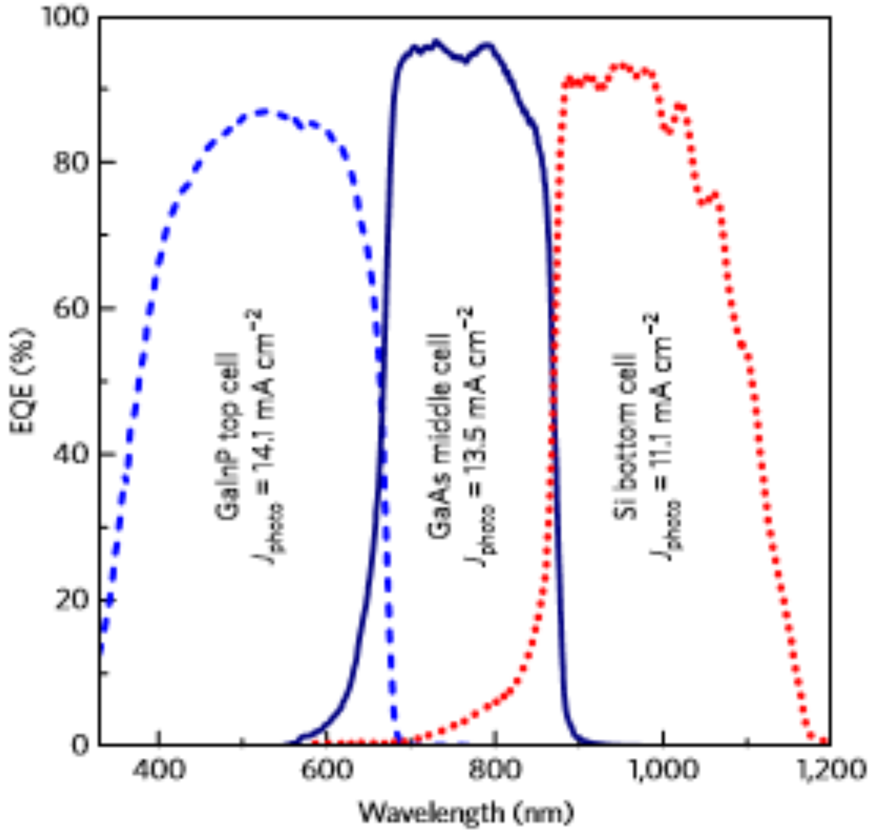


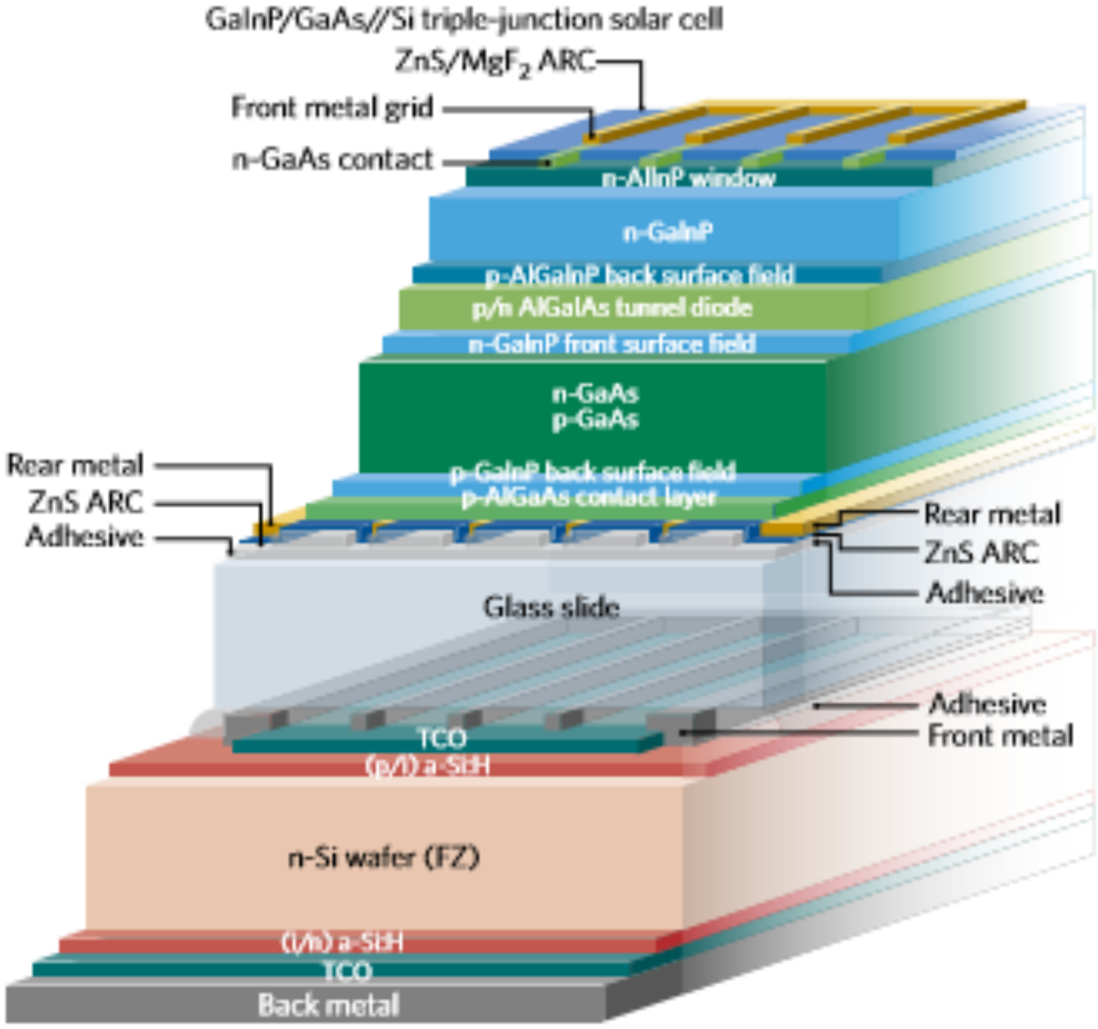
Bottom Cell : Si, CIGS…
Top Cell : PRX, III-V, CIGS…

nature energy
ARTICLES
PUBLISHED: 25 AUGUST 2017 | VOLUME: 2 | ARTICLE NUMBER: 17144

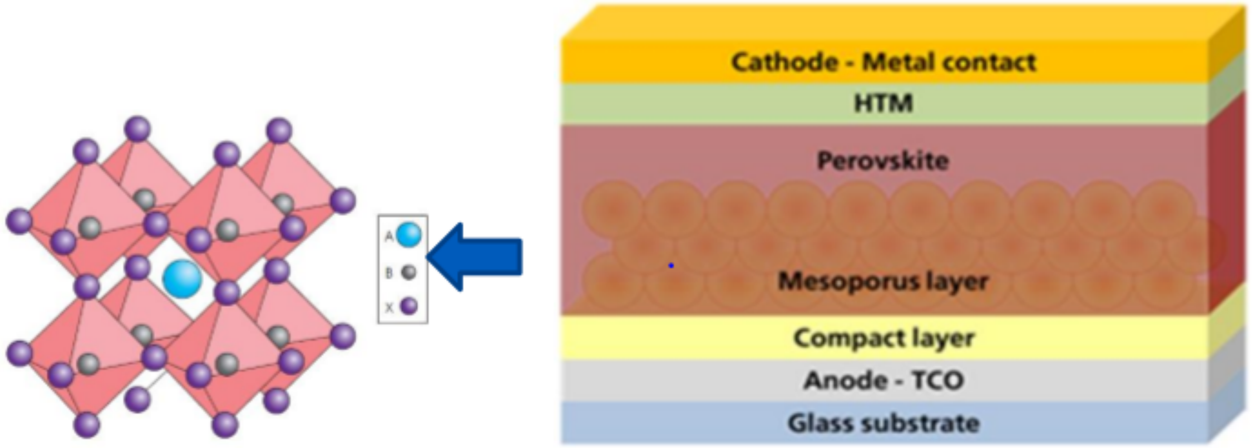
Raising the one-sun conversion efficiency of III–V/Si solar cells to 32.8% for two junctions and 35.9% for three junctions

Stephanie Essig[1]*, Christophe Allebé[2], Timothy Remo[3], John F. Geisz[3], Myles A. Steiner[3], Kelsey Horowitz[3], Loris Barraud[2], J. Scott Ward[3], Manuel Schnabel[3], Antoine Descoeudres[2], David L. Young[3], Michael Woodhouse[3], Matthieu Despeisse[2], Christophe Ballif[1,2] and Adele Tamboli[3]





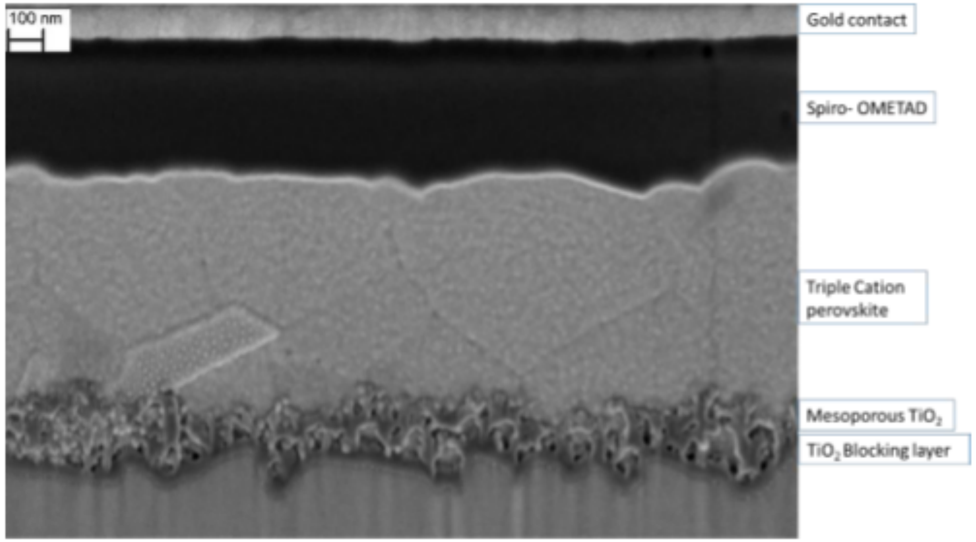
Perovskite Solar Cells : record efficiency 22.1% Eg=1.5 eV



Perovskite: ABX_3
A: $CH_3NH_3^+$ (MA), $NH_2CH{=}NH_3^+$ (FA)
Cs^+ , Rb^+
B: Pb^{2+} X: I^-, Br^-, Cl^-

AX	+	MX_2	—>	AMX_3
Organic		Inorganic		Perovskite

IPVF Results (Project F)

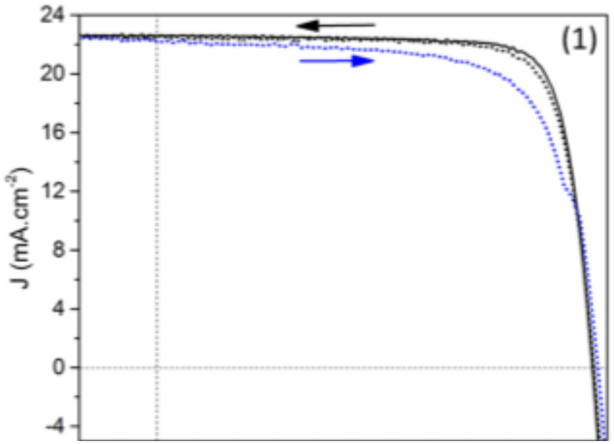


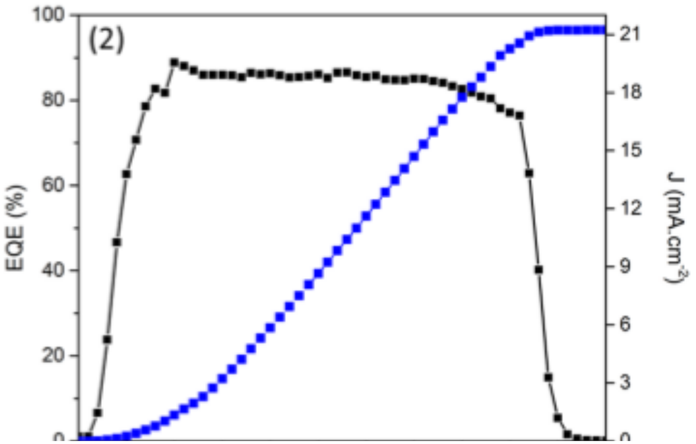
5 % Cesium introduced from CsI*
**Saliba et al. Energy environ. Sci., (2016).*

- ✓ FF improved
- ✓ Efficiency improved
- ✓ Stability improved
- ✓ Good reproducibility
- ✓ Record cell over 20 % / batch average over 18 %

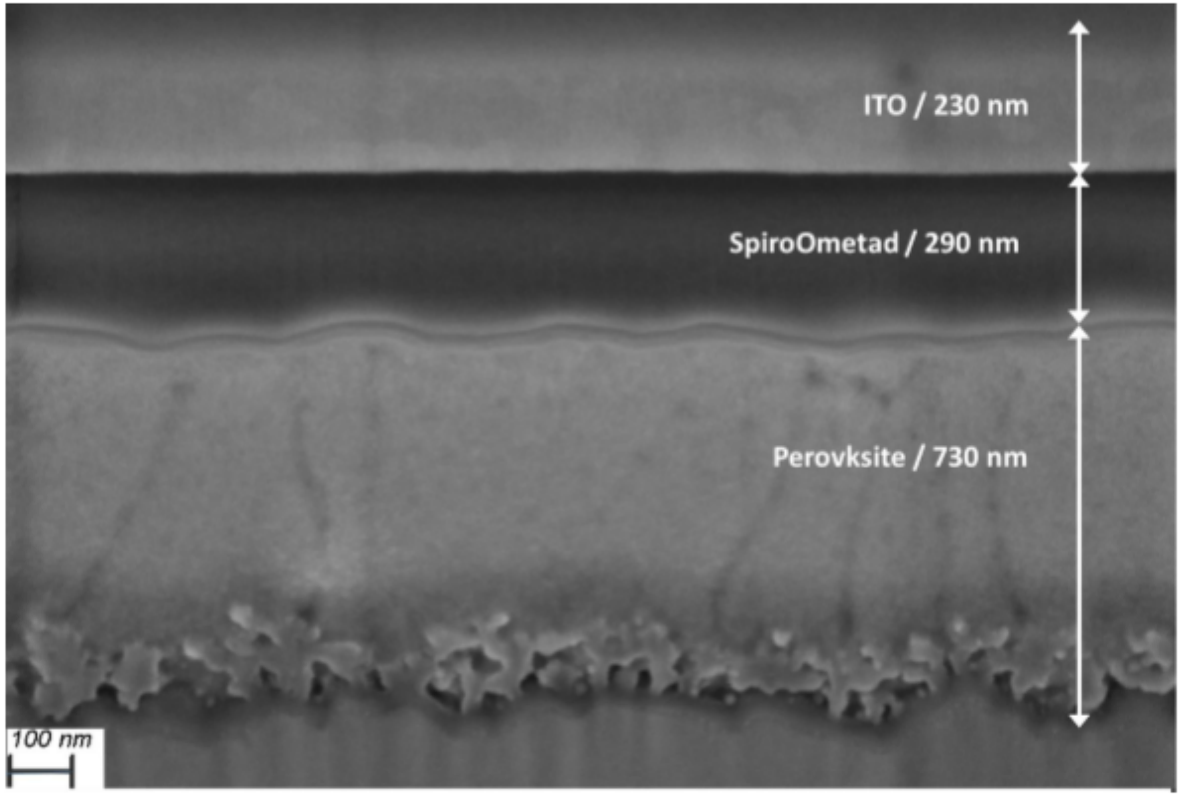
✗ Hysteresis still persists

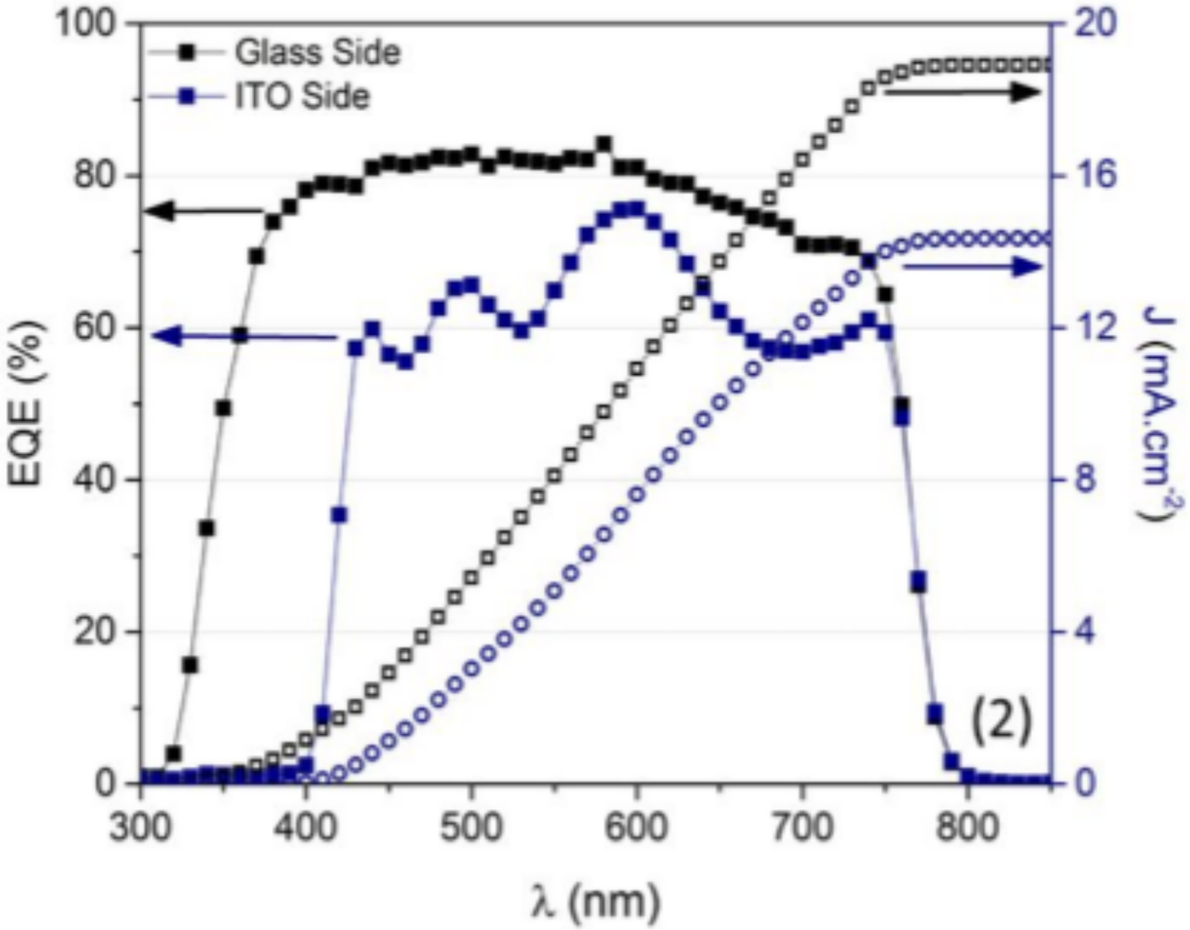
Reverse Scan	Forward Scan
J_{SC} =22.52 mA cm^{-2}	J_{SC} =22.23 mA cm^{-2}
V_{OC} =1103mV	V_{OC} =1120mV
FF = 80.8%	FF = 71%
Efficiency = 20.08%	Efficiency = 17.8%



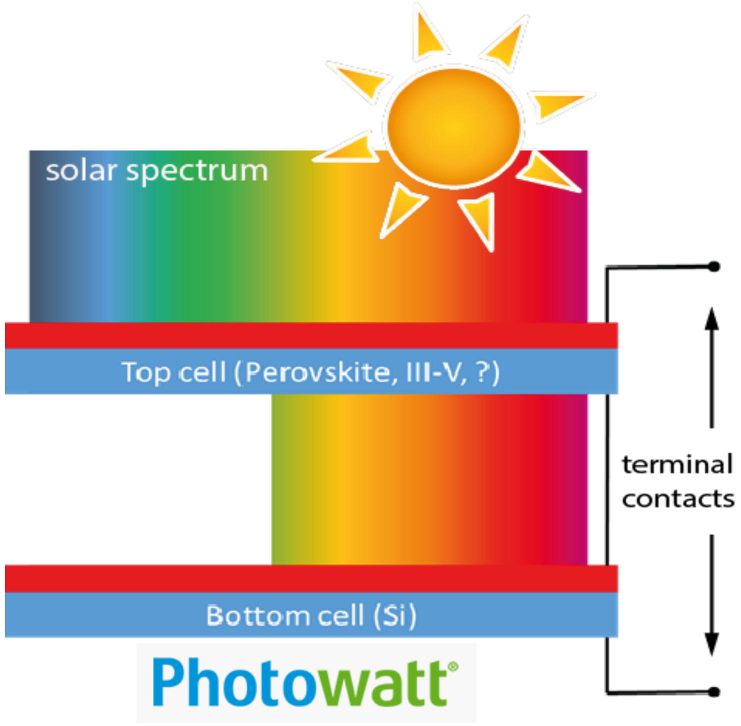


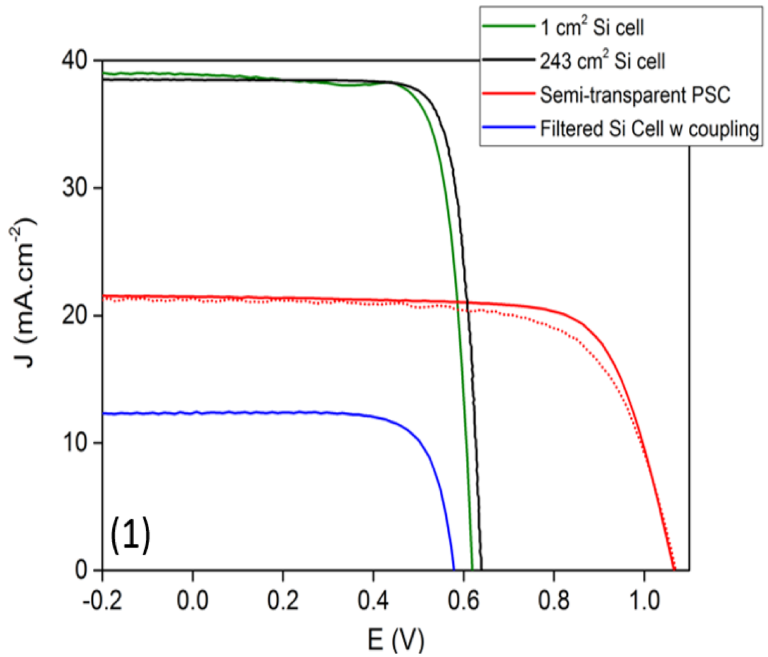
Semitransparent perovskite for tandem at IPVF

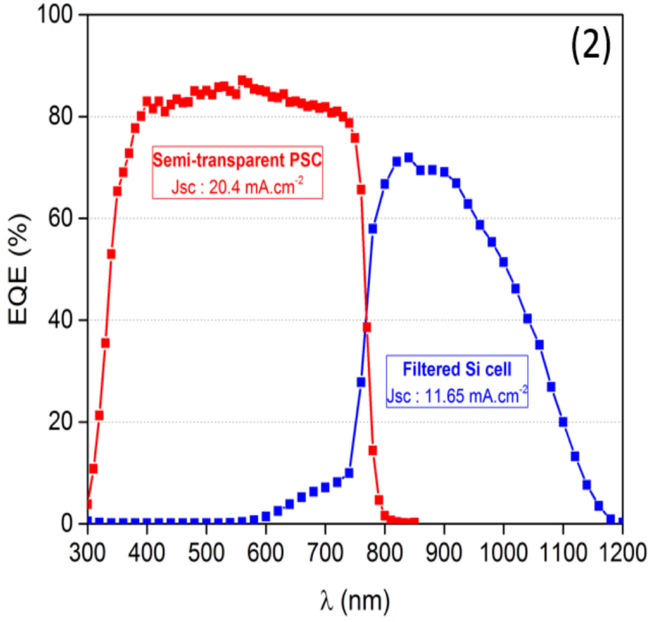




First tandem cells at IPVF : Si-Perovskites





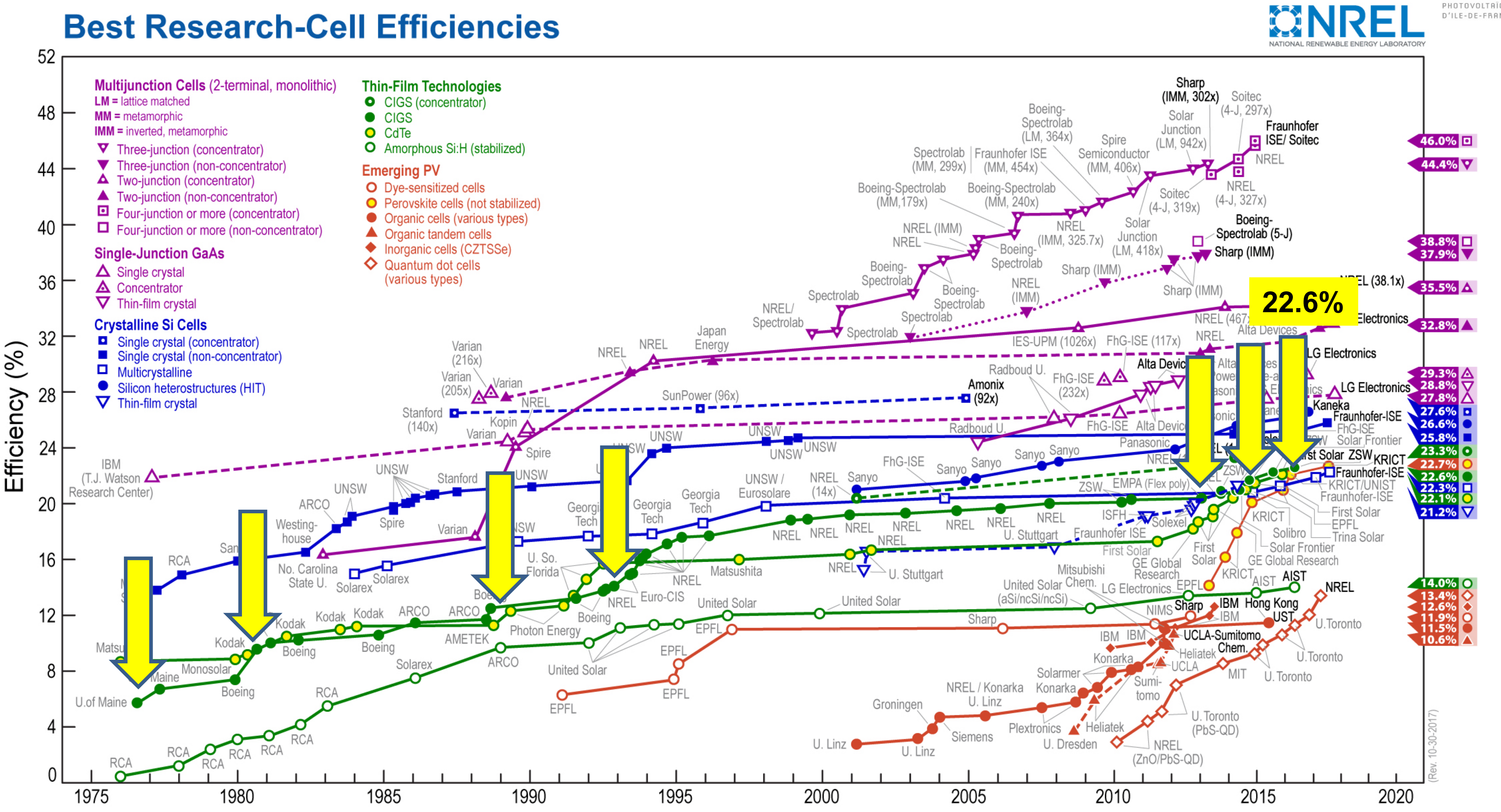


- Fabrication of a 17 % semi-transparent device and its test as a top cell of a 4T tandem device leading to 22.4 % potential efficiency

Copper Indium Galium diselenide solar cells (CIGS)

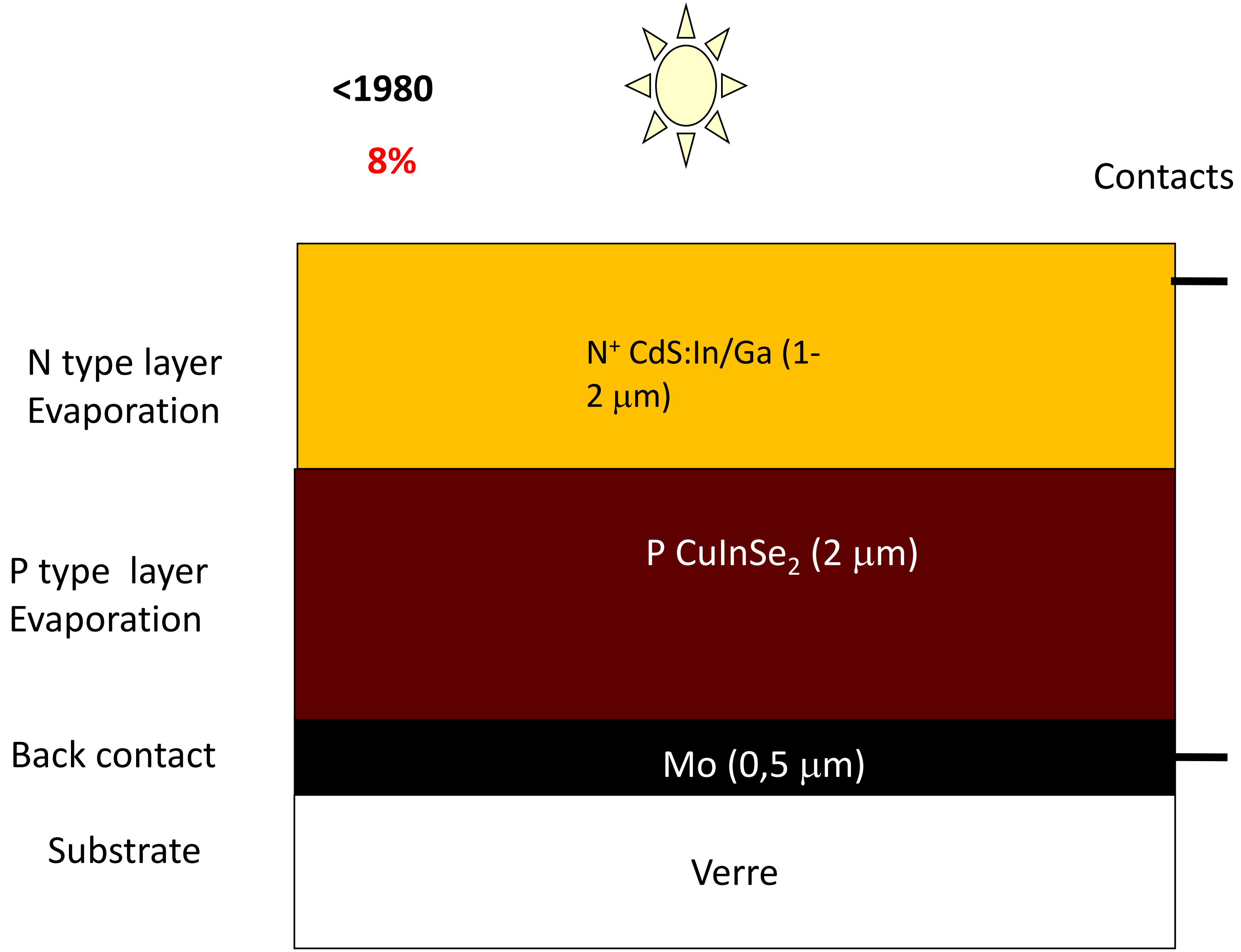
INSTITUT PHOTOVOLTAÏQUE D'ILE-DE-FRANCE

The research front of PV efficiency & technology competition



<1980

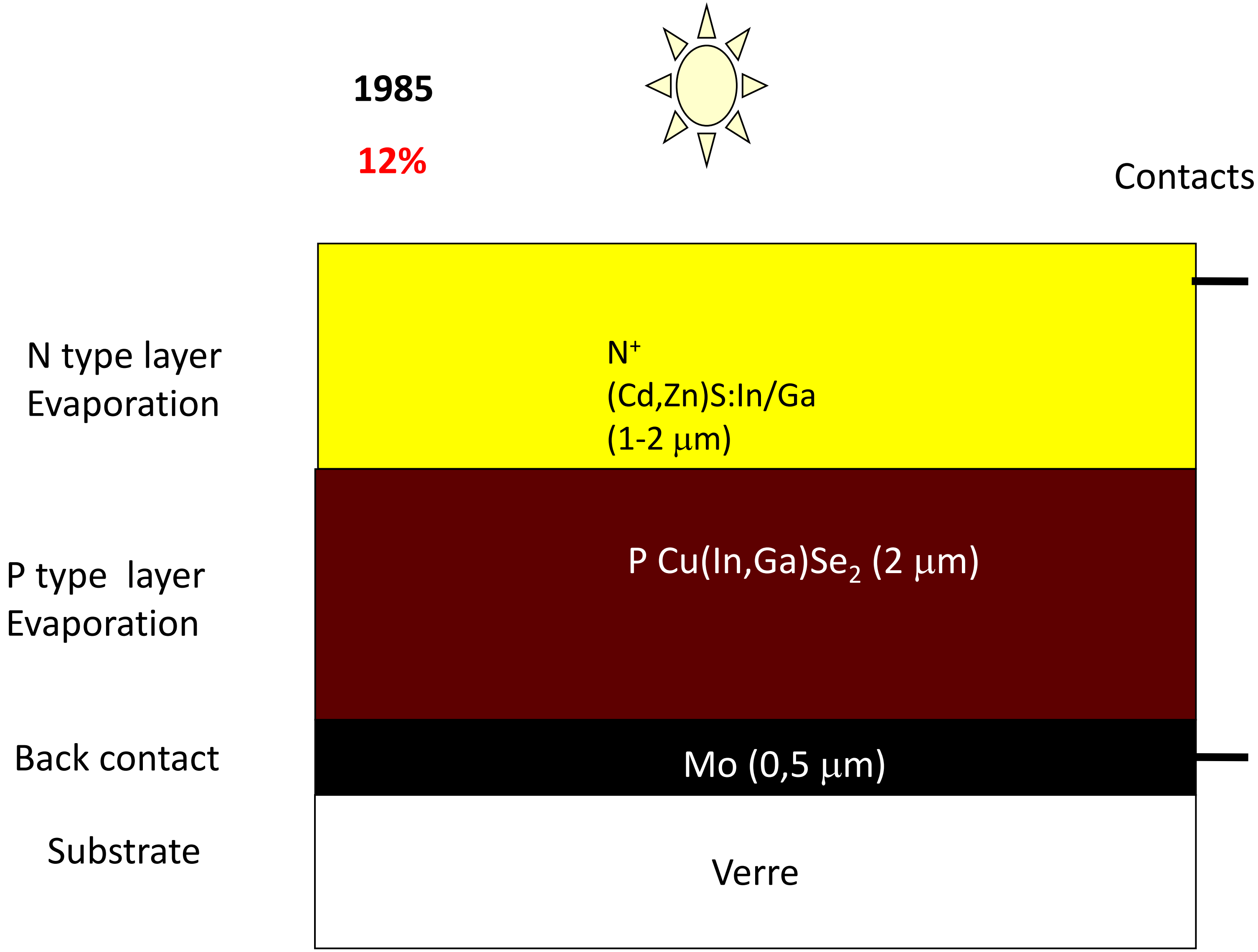
8%



Not to scale

1985

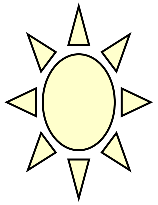
12%



Not to scale

1994

15%



Contacts

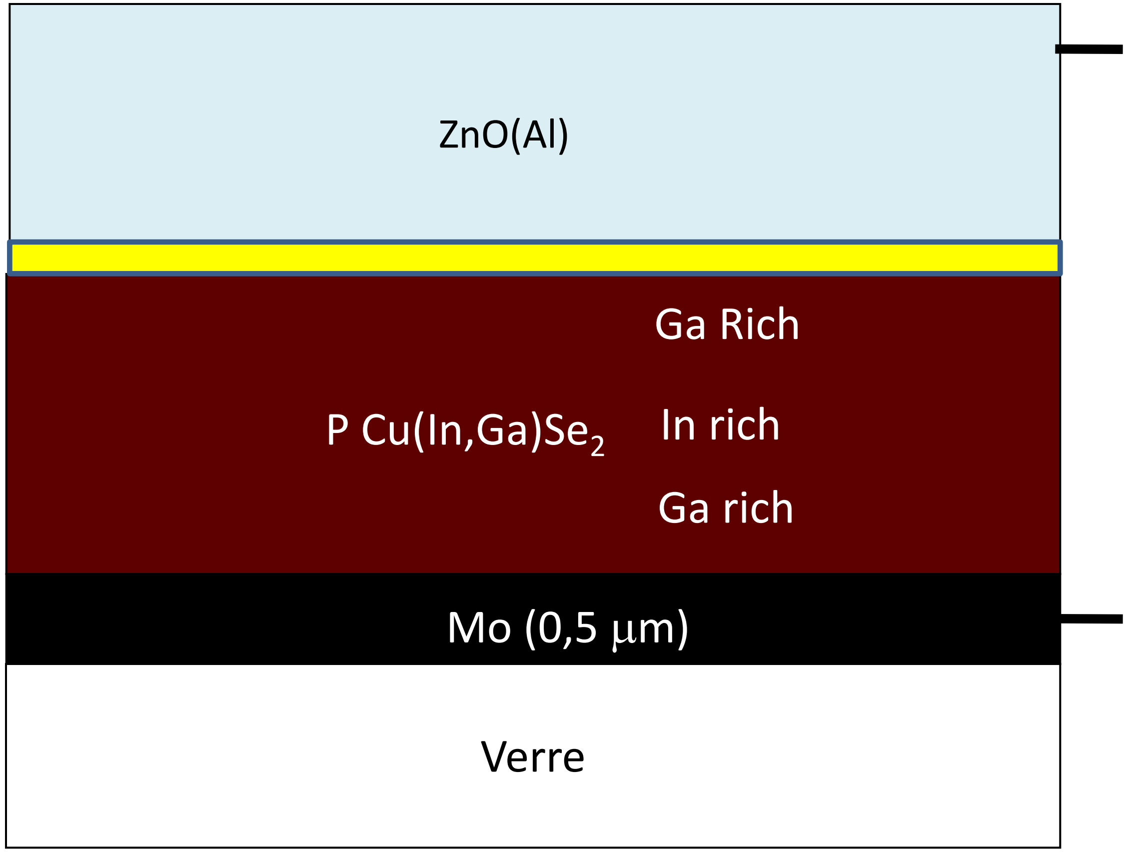
ZnO(Al)
By Sputtering

CdS by Solution (CBD)

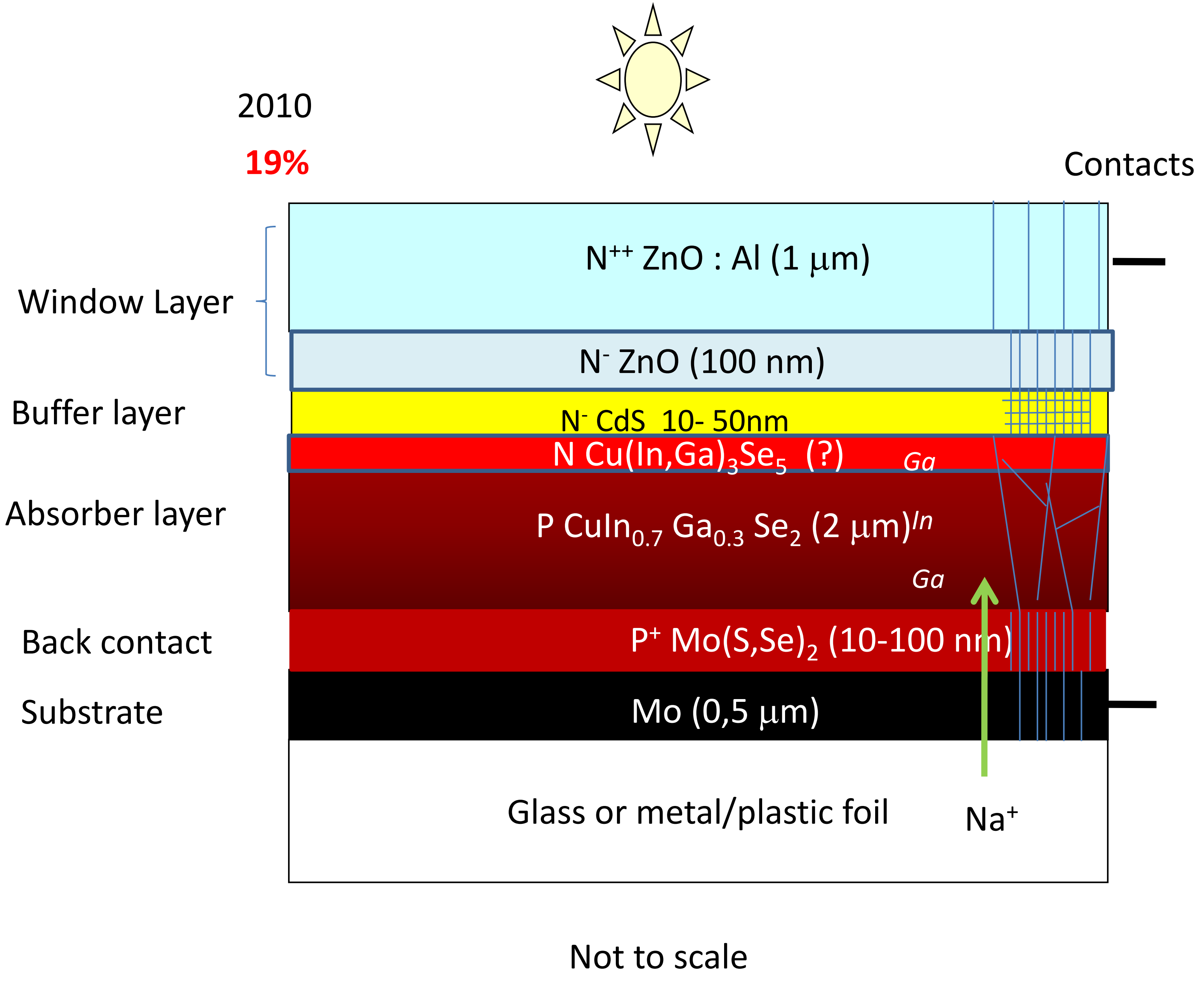
P type layer
By coEvaporation
3 stage process

Back contact

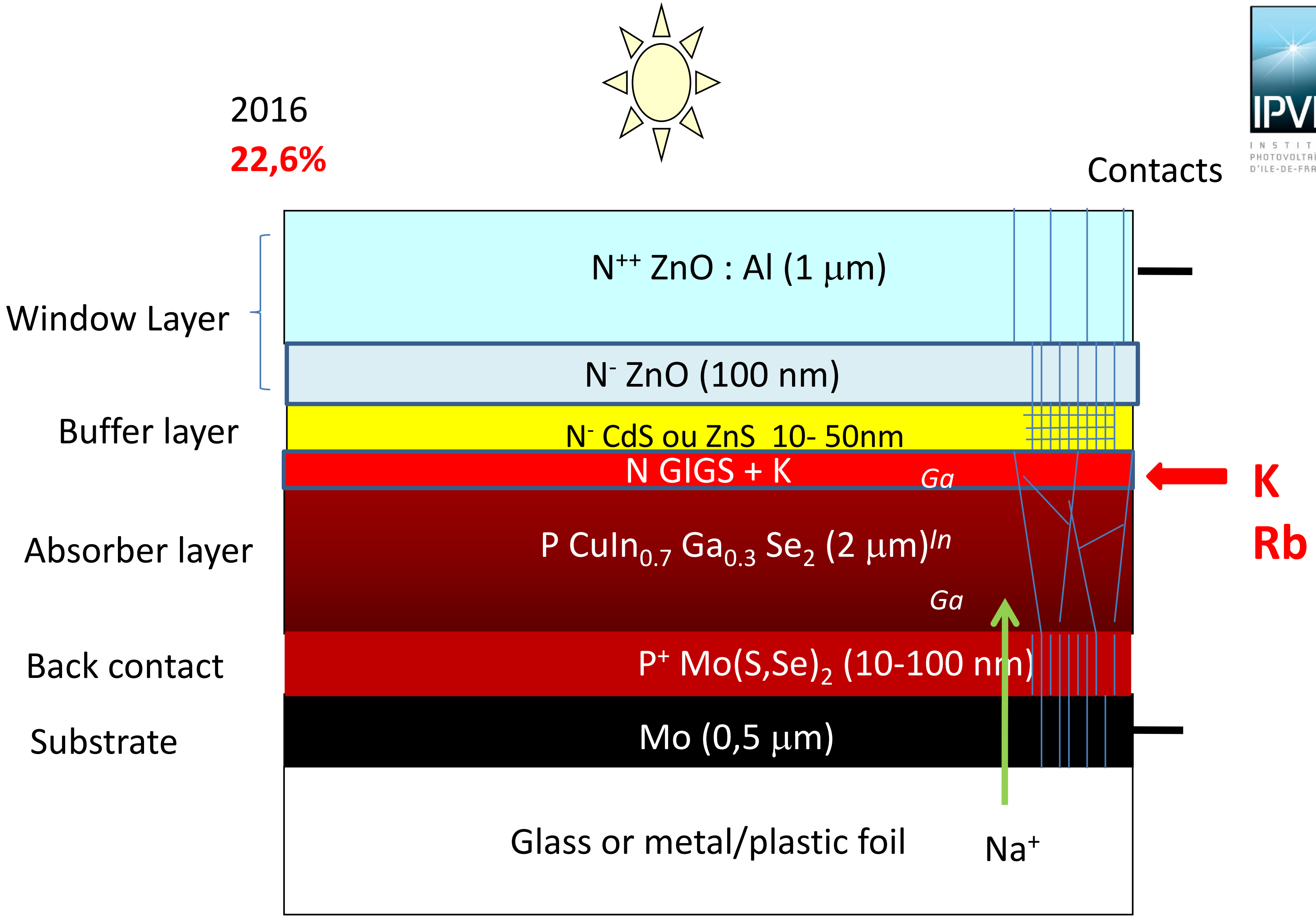
Substrate



Not to scale



2010
19%
Contacts
Window Layer
Buffer layer
Absorber layer
Back contact
Substrate
N++ ZnO : Al (1 µm)
N- ZnO (100 nm)
N- CdS 10- 50nm
N Cu(In,Ga)3Se5 (?)
Ga
P CuIn0.7 Ga0.3 Se2 (2 µm)
In
Ga
P+ Mo(S,Se)2 (10-100 nm)
Mo (0,5 µm)
Glass or metal/plastic foil
Na+
Not to scale


2016
22,6%
Contacts
Window Layer
N++ ZnO : Al (1 µm)
N- ZnO (100 nm)
Buffer layer
N- CdS ou ZnS 10- 50nm
N GIGS + K
Ga
K
Rb
Absorber layer
P CuIn0.7 Ga0.3 Se2 (2 µm)
In
Ga
Back contact
P+ Mo(S,Se)2 (10-100 nm)
Substrate
Mo (0,5 µm)
Glass or metal/plastic foil
Na+

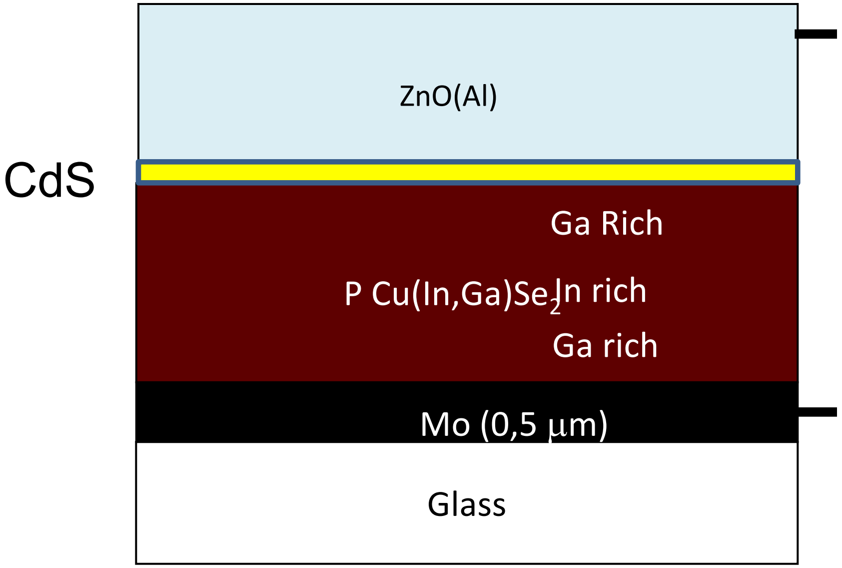
Not to scale

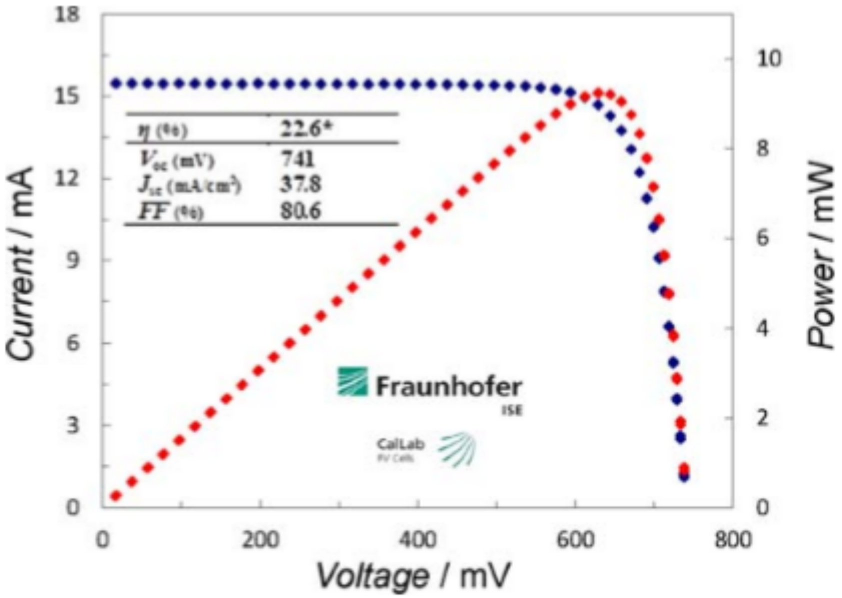
Wiley Online Library
Early View publication on www.wileyonlinelibrary.com
(issue and page numbers not yet assigned;
citable using Digital Object Identifier – DOI)

Phys. Status Solidi RRL, 1–4 (2016) / DOI 10.1002/pssr.201600199

Effects of heavy alkali elements in $Cu(In,Ga)Se_2$ solar cells with efficiencies up to 22.6%

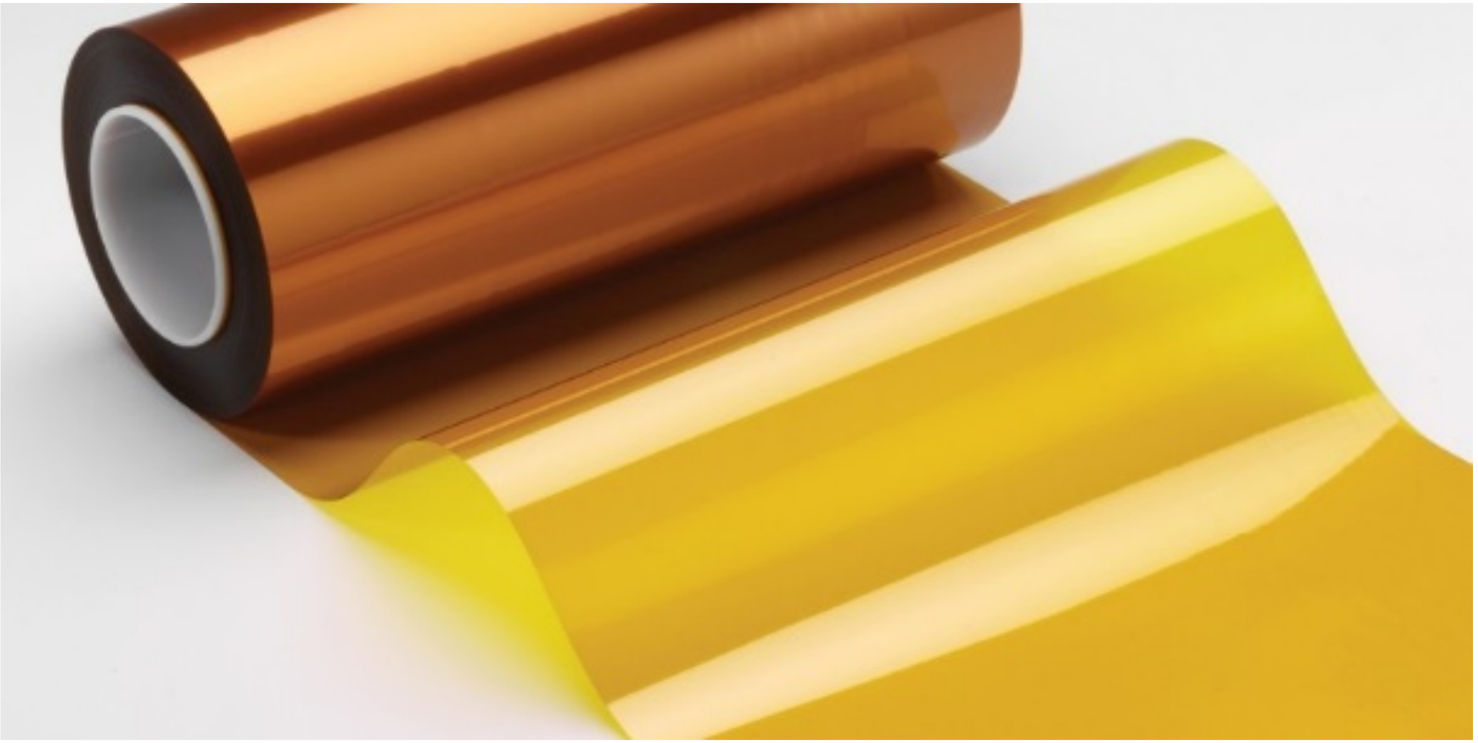
Philip Jackson*, Roland Wuerz, Dimitrios Hariskos, Erwin Lotter, Wolfram Witte, and Michael Powalla



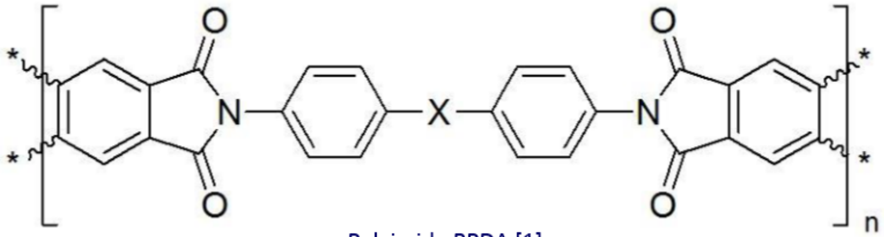


IPVF Project B : Ultralight Weight CIGS cells on Plastics

High Temperature Polymer (up to 450°C)
From 5 microns to 50 microns thickness
50g/m^2 instead of 7 kg/m^2

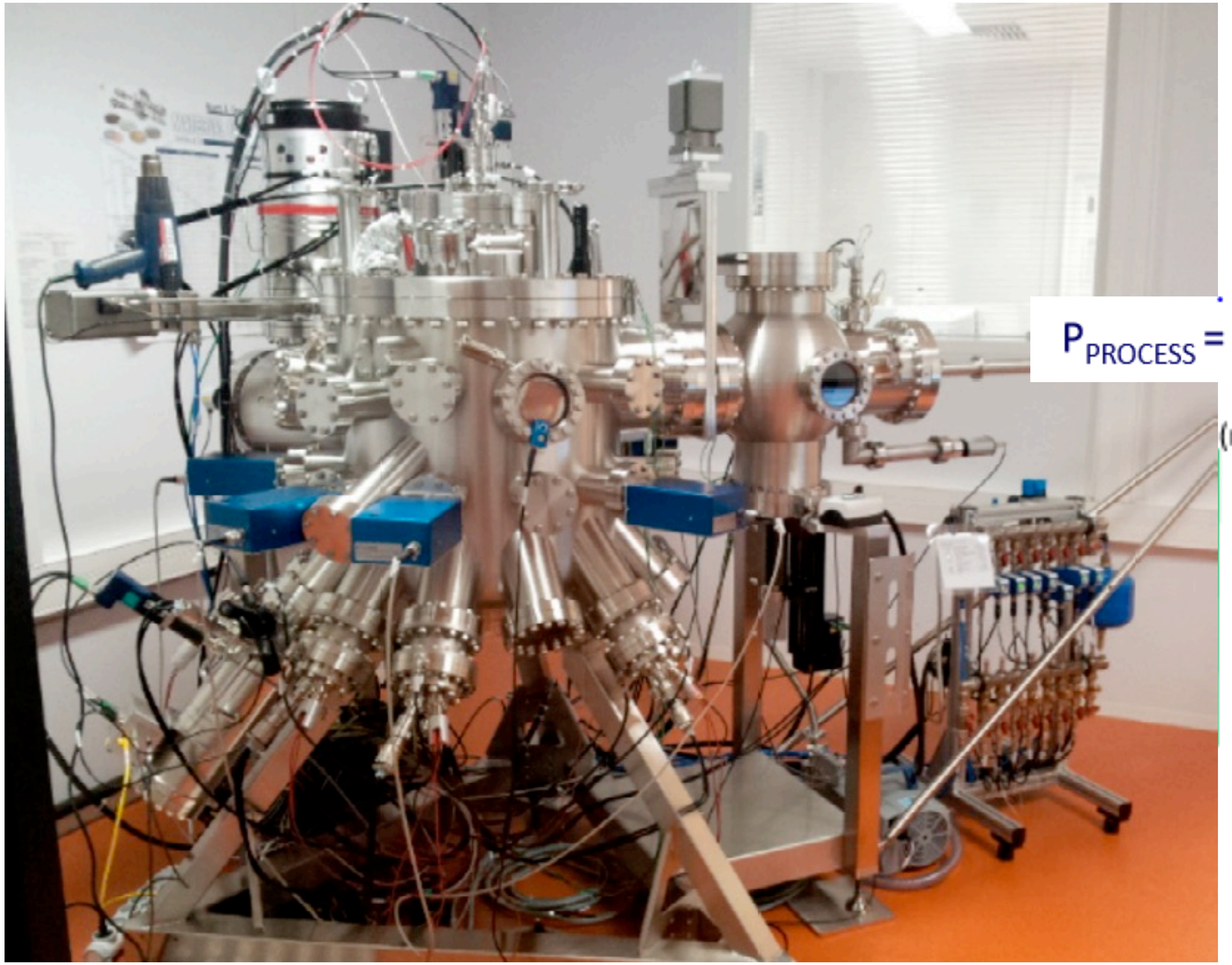


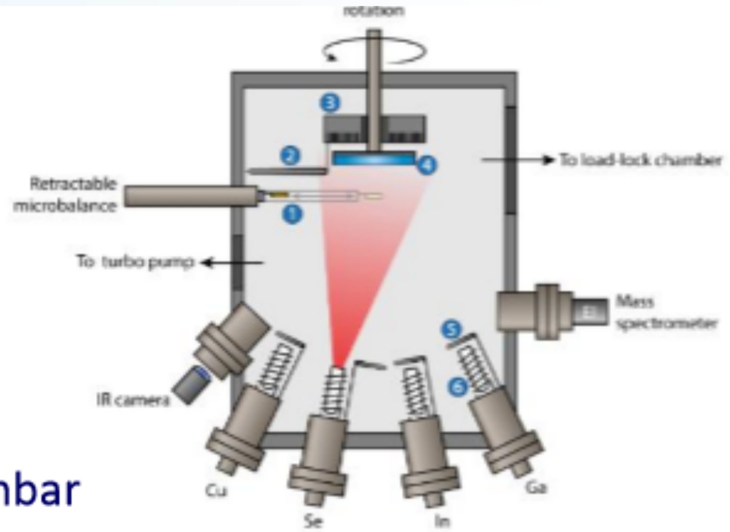
POLYIMIDE



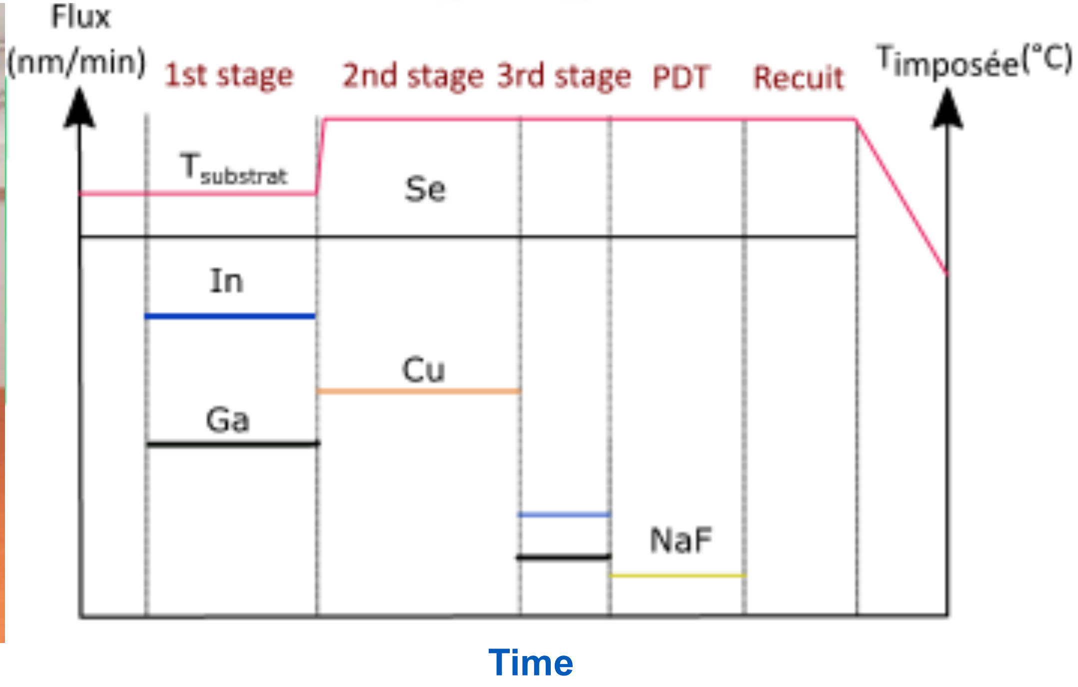
Polyimide BPDA [1]

Deposition of CIGS by Ultra High Vacuum Coevaporation





$P_{PROCESS} = 10^{-7}$ mbar

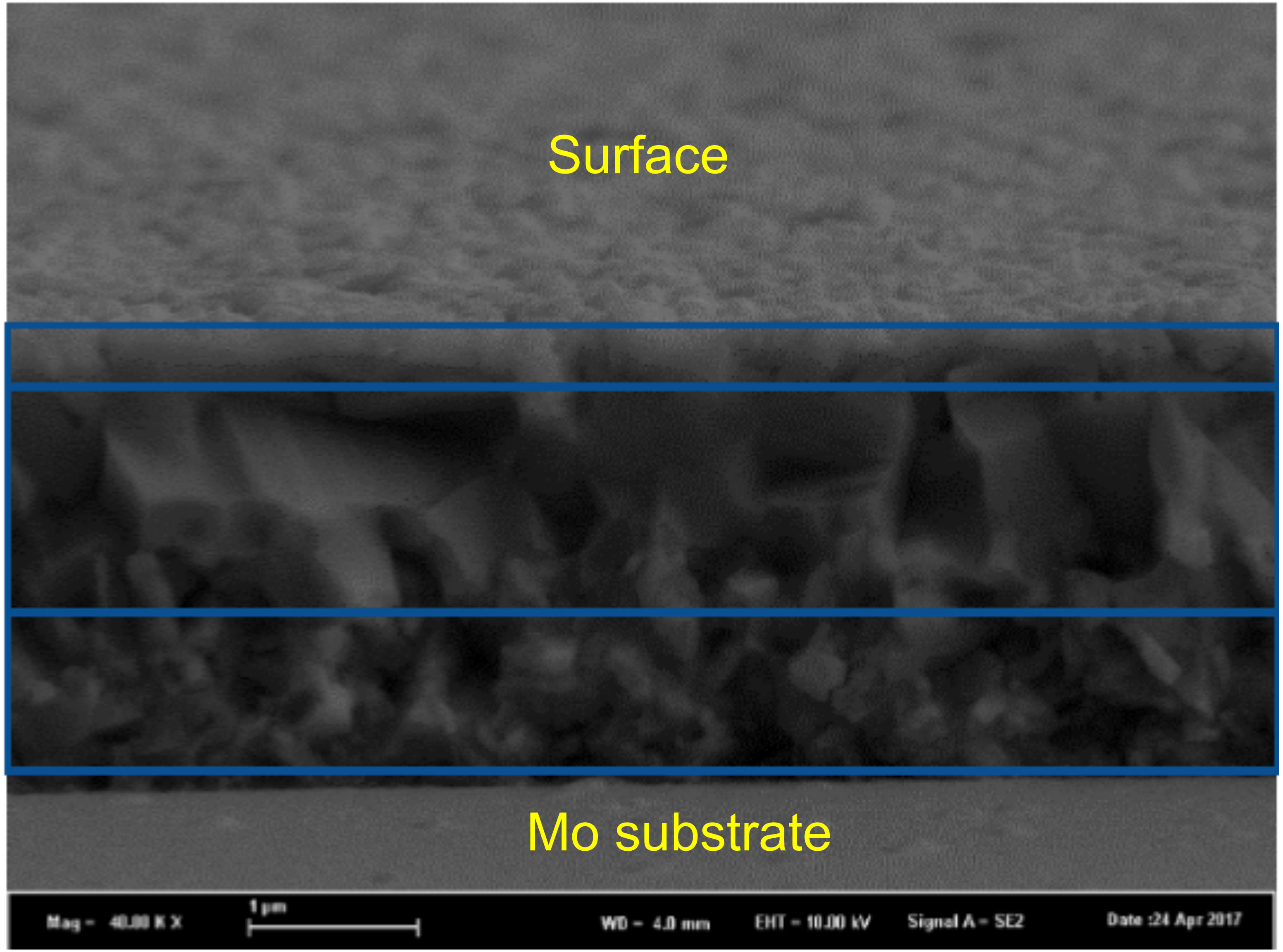


How looks CIGS layer ?

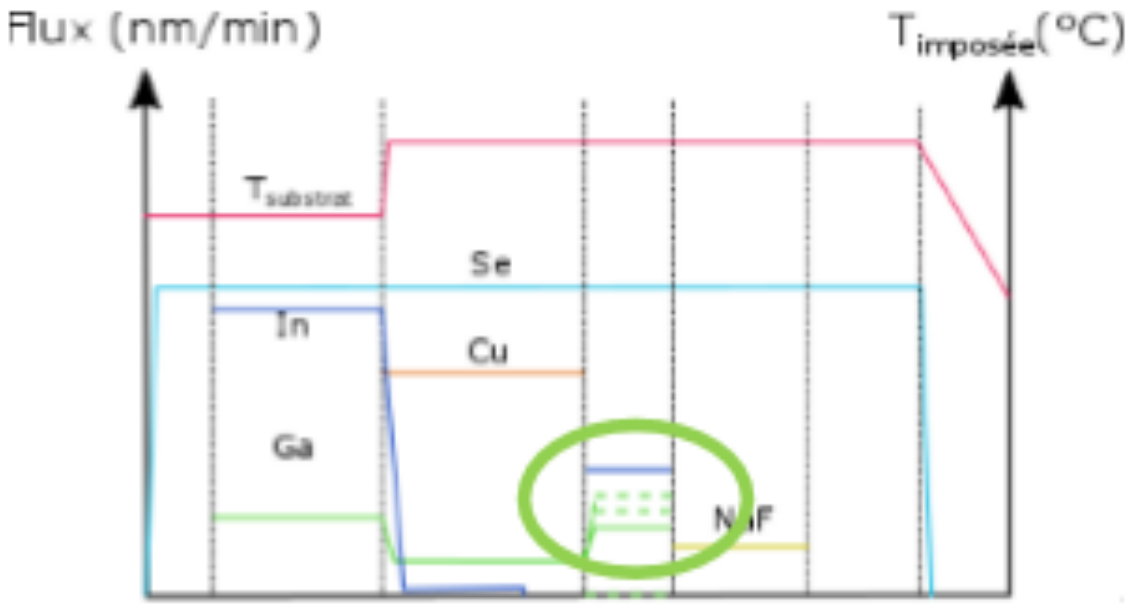
Third Stage

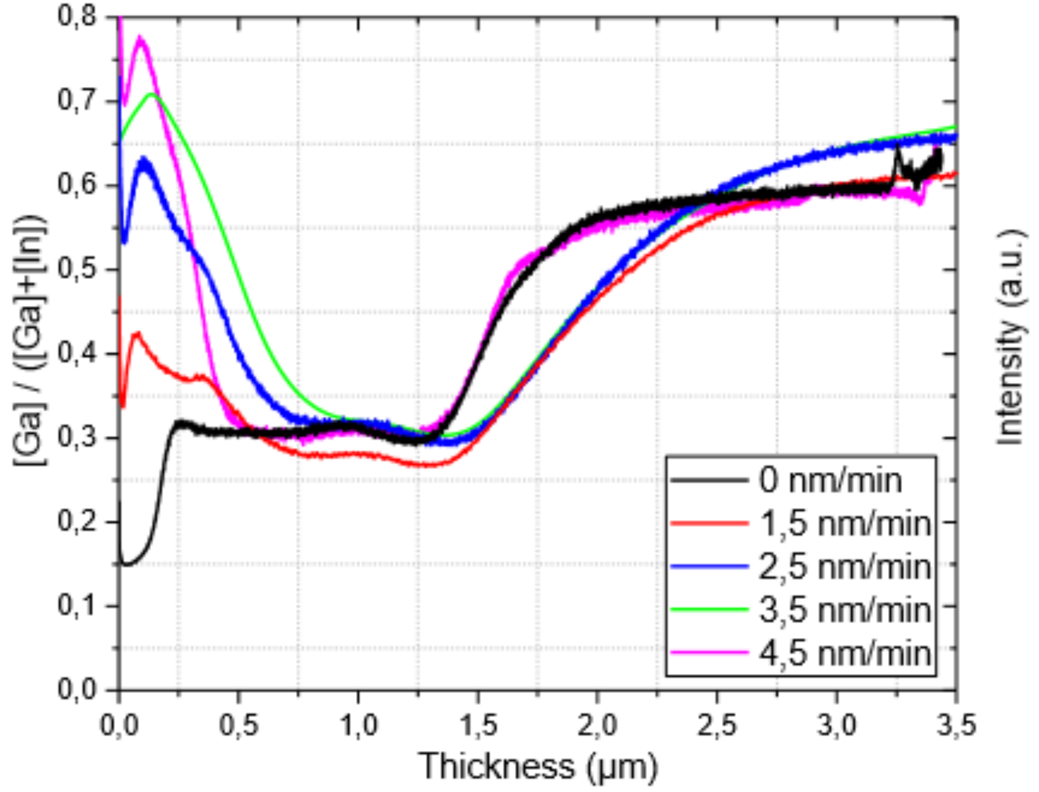
Second Stage

First Stage

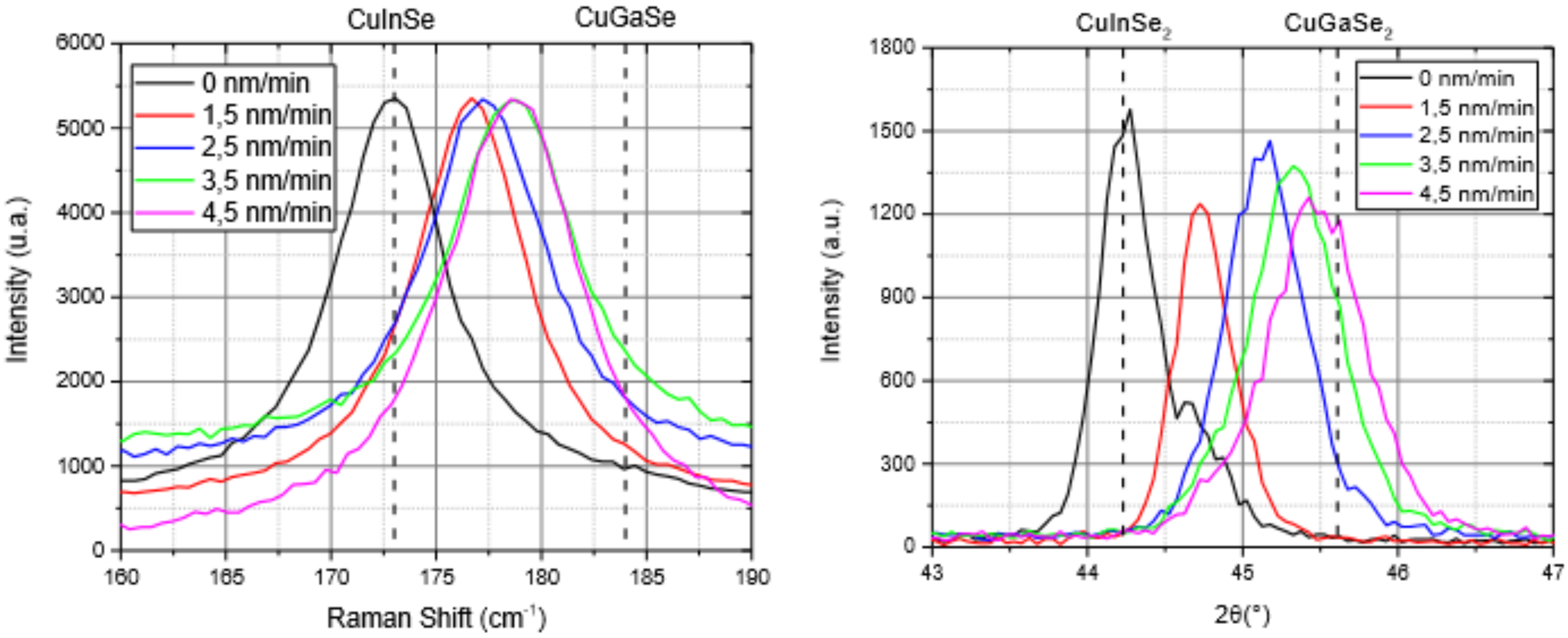


Influence of Gallium concentration at the surface





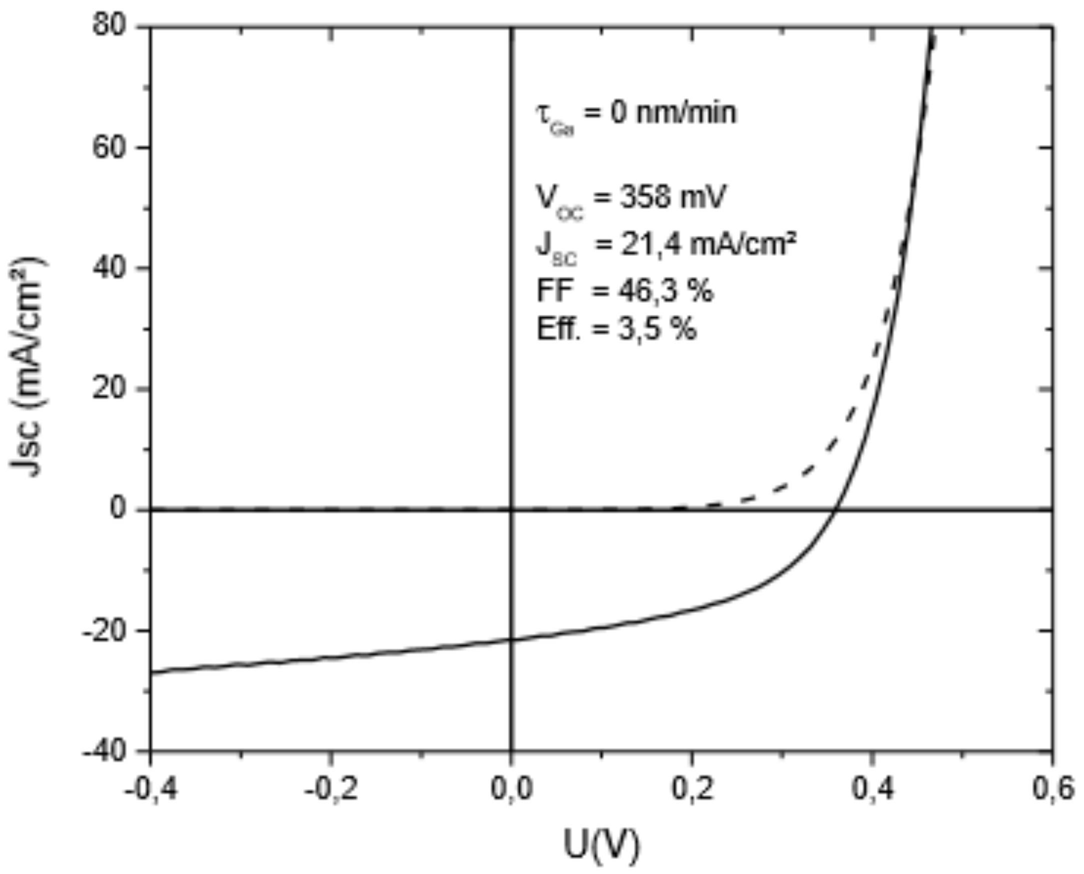
Surface Studies by RAMAN and Grazing Angle XRD



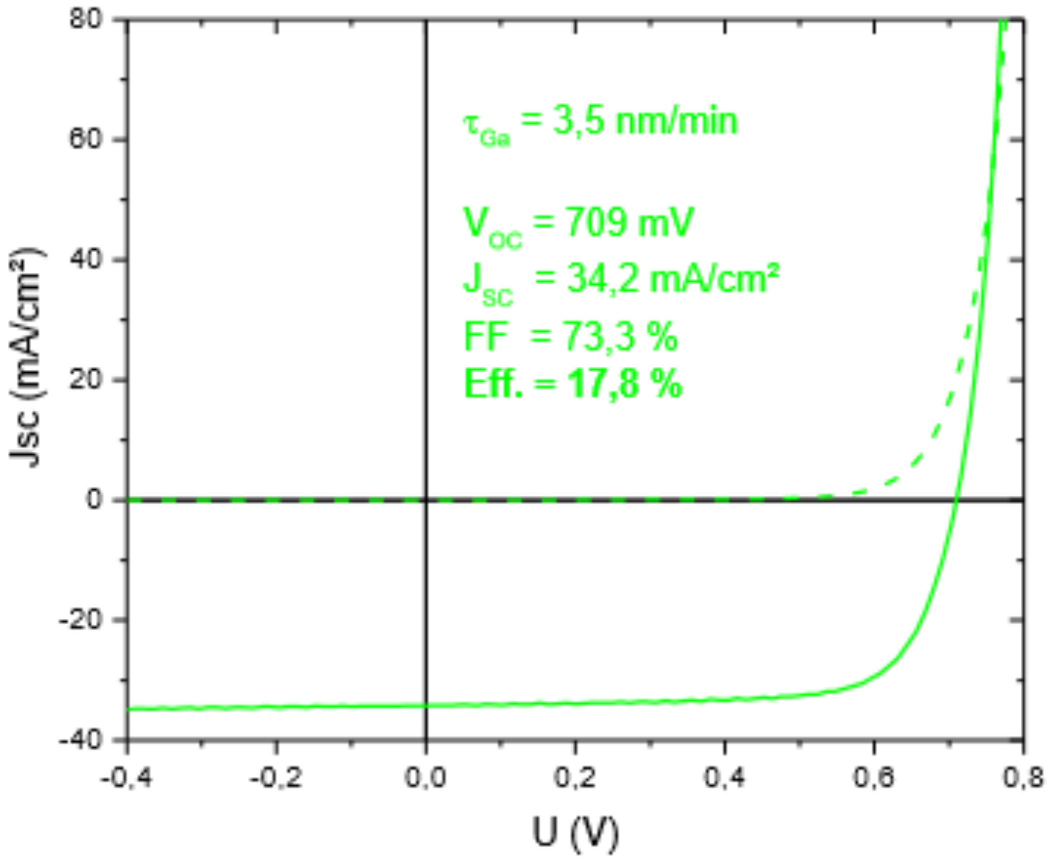
Increased Raman shift : Ga rich phases formed at the interface
GiXRD measurements showed that those phases are cristalline
FWHM ↗ with Ga ↗ : stronger gradient at the front contact

Impact on Photovoltaic Properties

Indium rich surface : 3,5 %

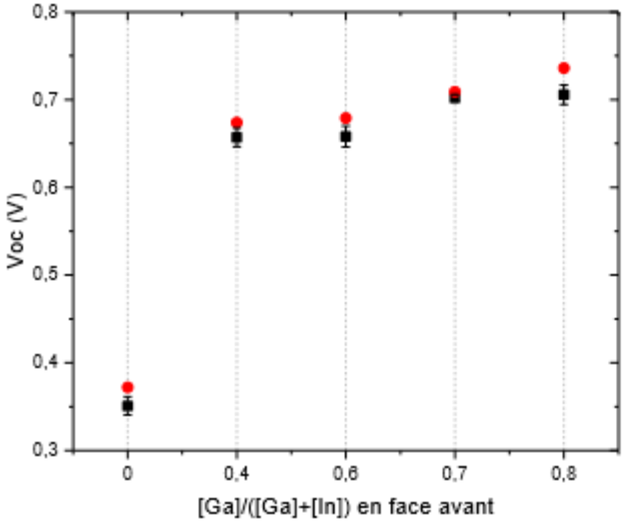


Gallium rich surface : 17.8 %

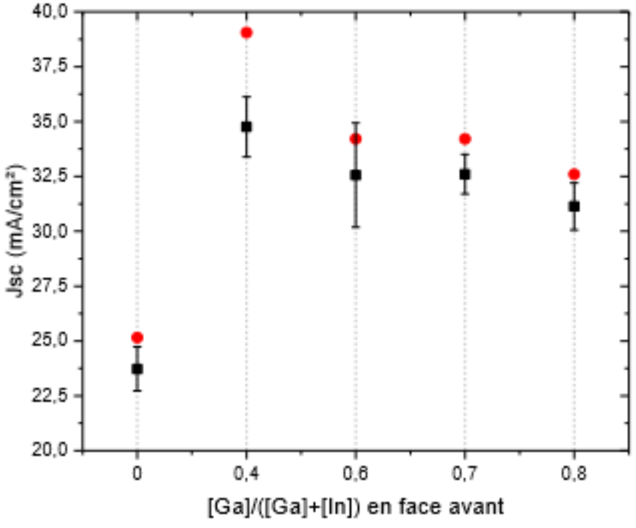


Optimization Studies

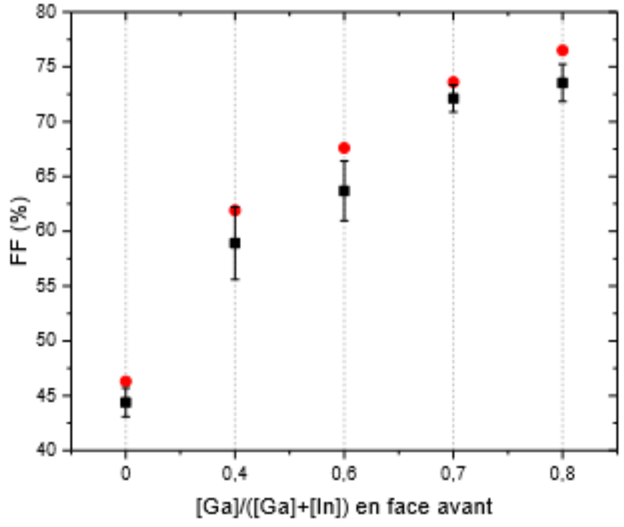
Open Circuit Voltage



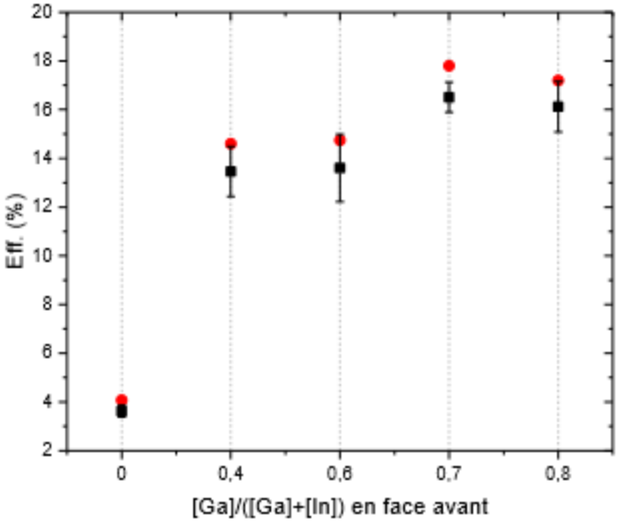
Short Circuit Current



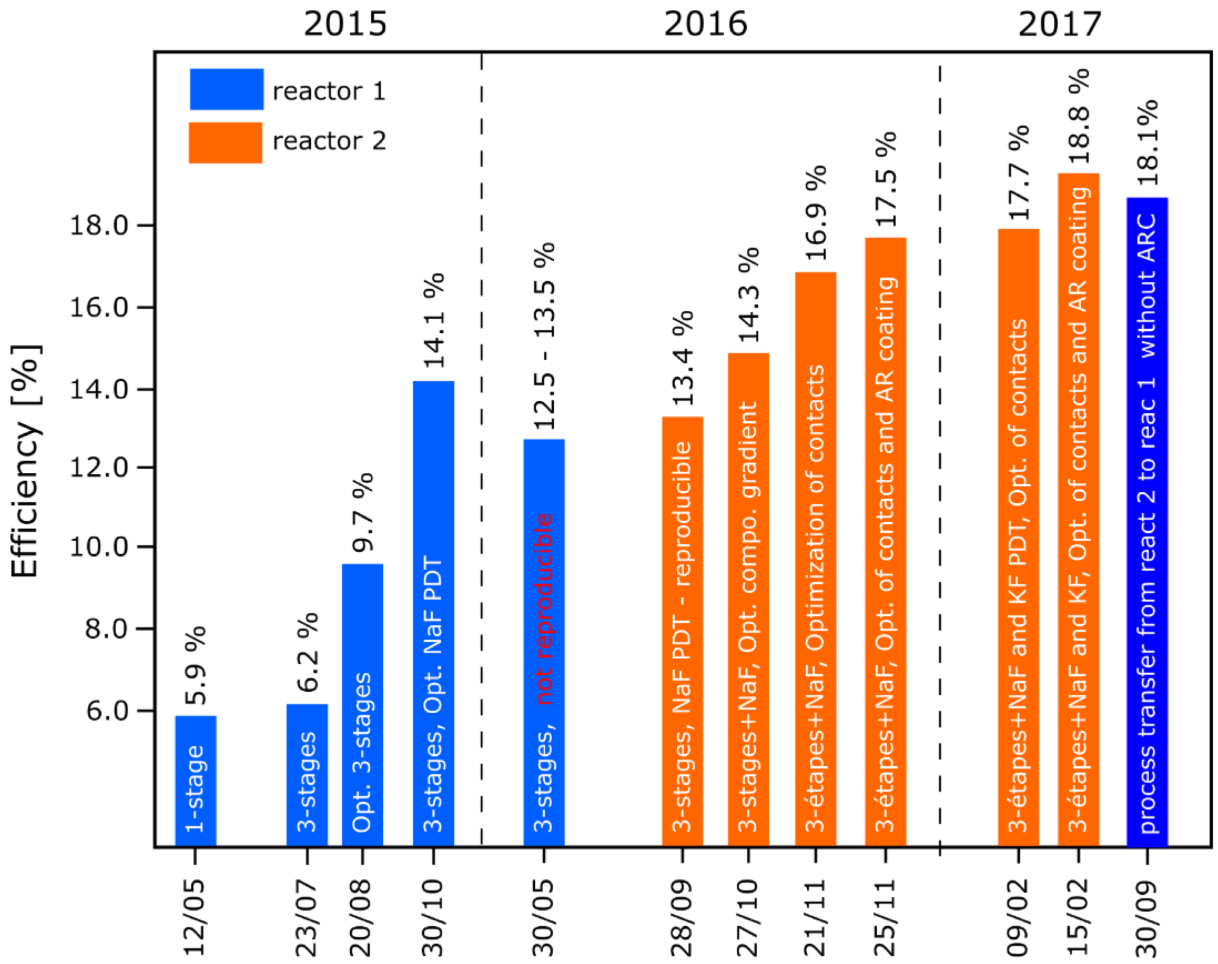
Fill Factor



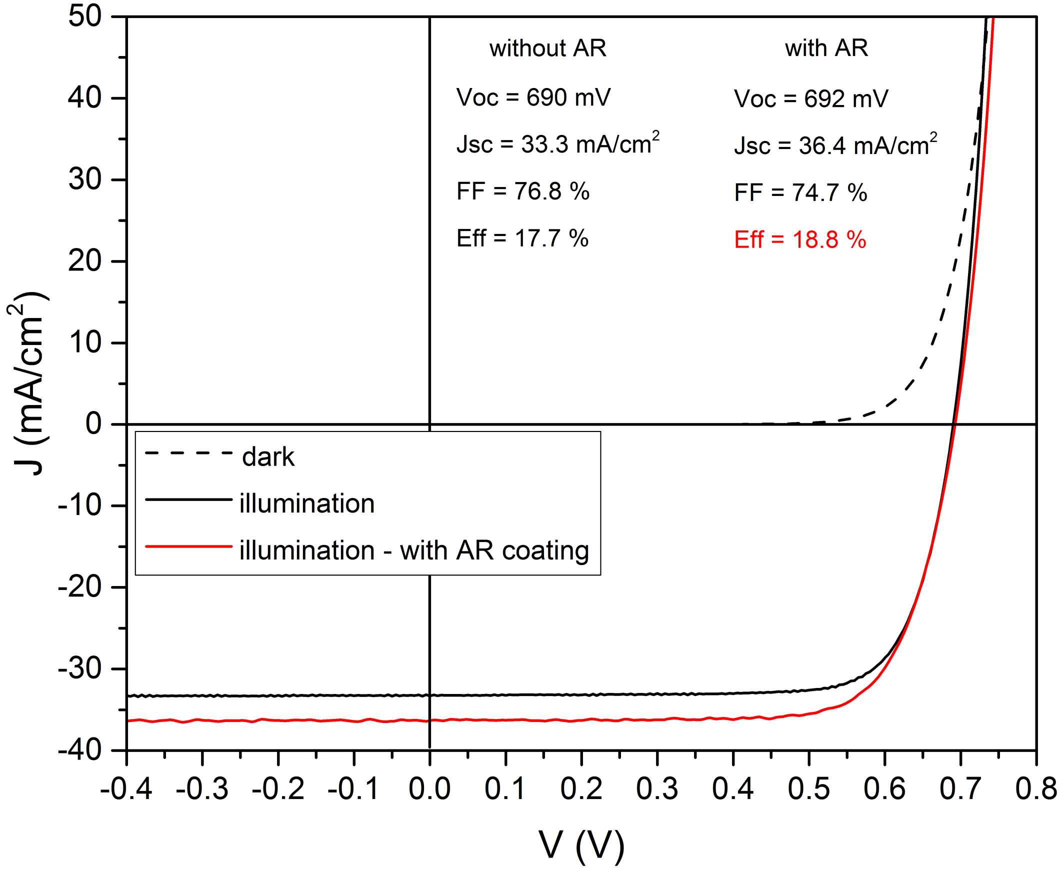
Efficiency



Result of Optimization Studies



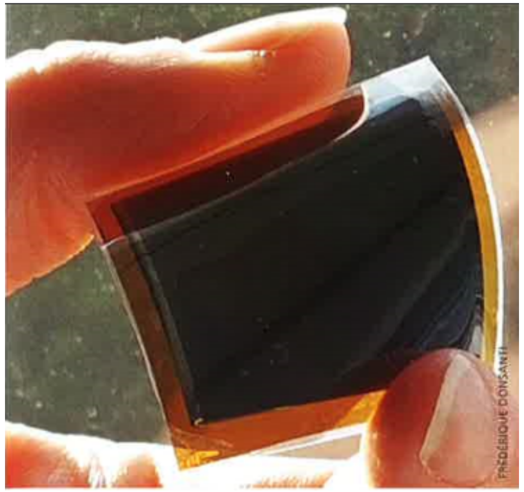
18.8% Efficiency



European Partnership

ZSW : World record
on CIGS on glass
22,6%

IPVF : World Class
on CIGS on Plastic
18.8%%



IPVF-2018-DPV-15

Press Release

Paris / Stuttgart, January 18, 2018

ZSW and IPVF Launch Cooperation in CIGS Thin-film Photovoltaics

Focus on Flexible Light Weight CIGS Solar Cells

Jean-François Minster, President of IPVF, and Michael Powalla, Member of the Board, ZSW, signing the Memorandum of Understanding at ZSW Stuttgart. (Photo: ZSW)

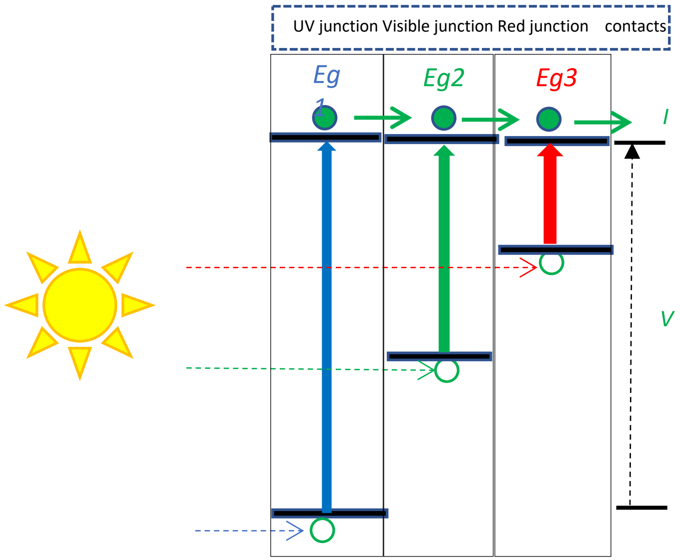
Project D : Ultra high Efficiency Concepts (> 50%)

Short Term

Fundamental research Long term

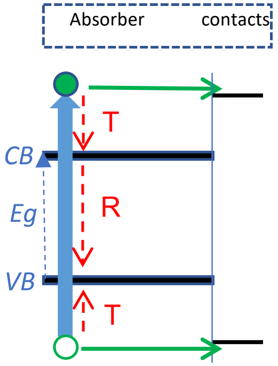
A

Multi-junctions Solar Cell



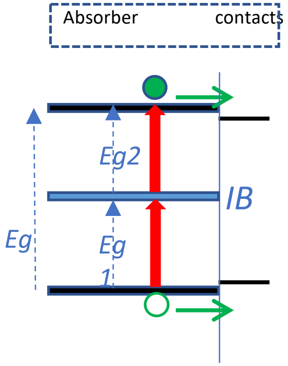
B

Hot Carrier Solar Cell



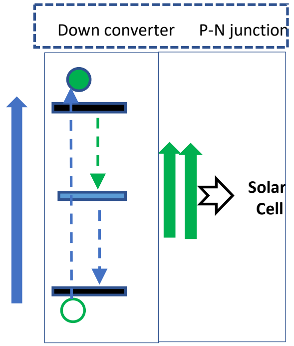
C

Intermediate Band Solar Cell



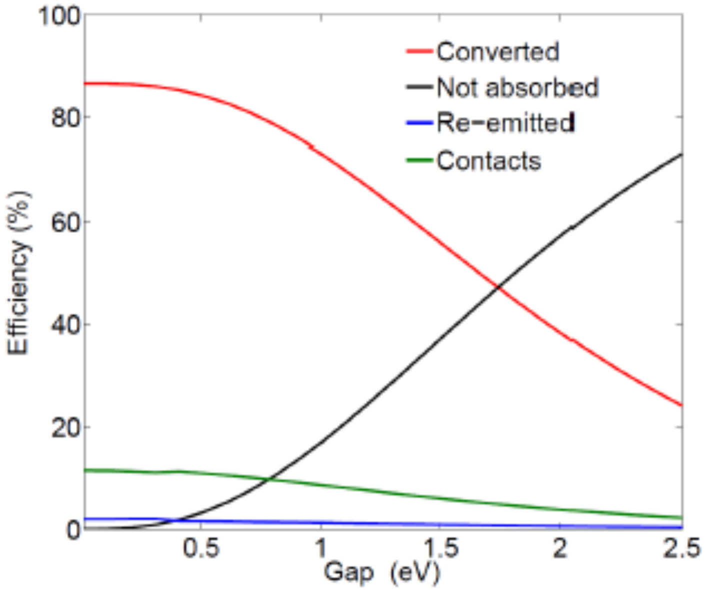
D

Down Conversion Solar Cell



The hot carrier device : the Ultimate PV cell

- **Idealized (thermodynamic) hot carrier solar cell model**
  - ✓ Radiative recombination limit
  - ✓ Suppressed thermalization
  - ✓ Perfect absorption and carrier collection
- **Idealized multijunction cell model**
  - ✓ Radiative recombination limit
  - ✓ Perfect absorption and carrier collection



Type of cell	Single junction (*Shockley – Queisser*)		Infinite stack (*De Vos*)		Ideal HCSC (*Würfel*)	
Concentration	Full conc.	Unconc.	Full conc.	Unconc.	Full conc.	Unconc.
Max efficiency	41 %	31 %	86.8 %	68.2 %	86 %	67 %

Only a concept at this point

Photovoltaics and Society

- Example of a joint initiative in 2017 at the interface between Human & Social Sciences and Photovoltaics on the Saclay's area

Journée "Sciences Humaines et Sociales & Photovoltaïque"

25 Avril 2017 – de 09h00 à 17h30
(CEA Saclay – l'Orme des Merisiers - Amphi Claude Bloch)

Additional Transparencies : Case examples

Le développement centralisé : Les grandes fermes photovoltaïques

Ferme solaire Longyangxia Dam, Chine. Crédit : NASA

1- Chine, Qinghai, Février 2017
Inauguration de la plus grande ferme solaire du monde en Chine, **Longyangxia Dam**

27 km^2

4 millions de panneaux solaires
850 MW

2- Inde, Kamuthi, 648 MW

3- USA, Californie, Topaz, 579 MW

13-France, Cestas, 300 MW (2015)

En projet : Chine, Ningxia, 2 GW

Le développement décentralisé en milieu urbain et agricole

Mouvement de fond

Lien avec le développement de l'autoconsommation/stock
Mobilité électrique solaire
Habitat à énergie positive
Nouvelles ressources financières (énergieculteurs)
Développement de modèles d'économie collaborative

Une multiplication des innovations

Route Solaire

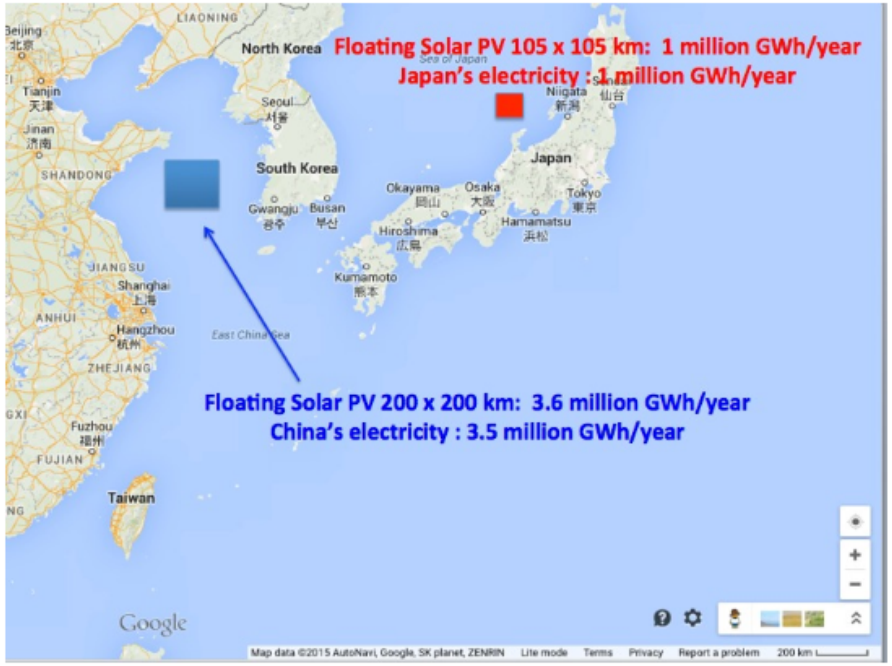
Avion solaire

Photovoltaïque flottant

Photovoltaique déployable

FLOATING SOLAR – A CRAZY BIG IDEA?

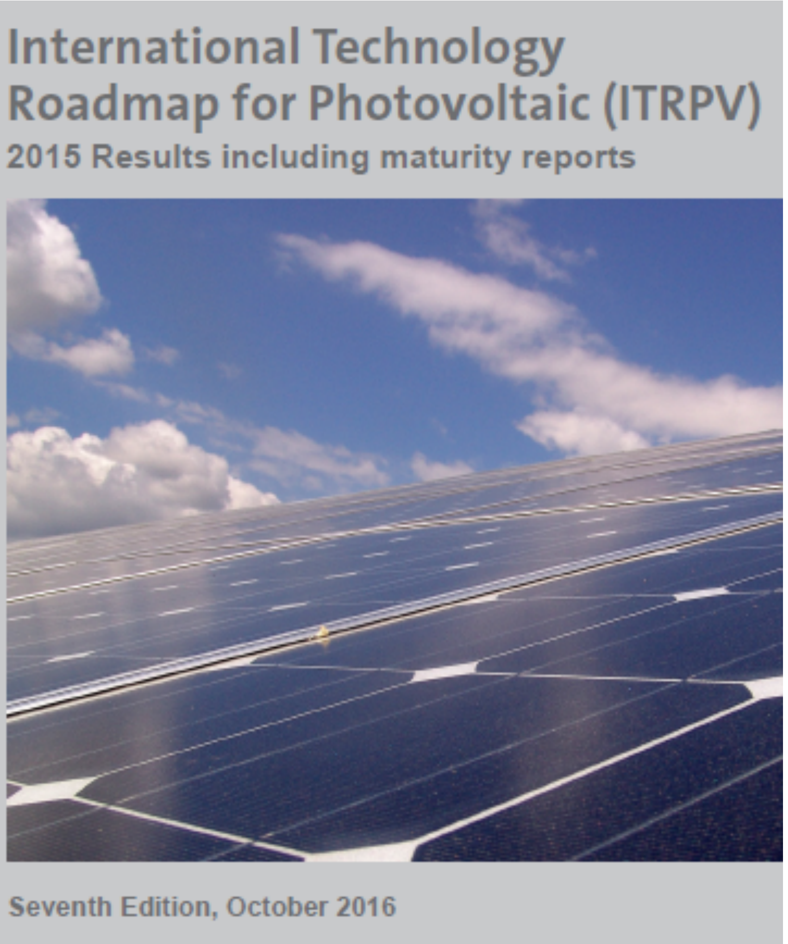
Call me crazy, but I find it fascinating.



See also: India Plans World's Largest Floating Solar Power Project (50 MW)

Conclusions : What's Next ?

IPVF INSTITUT PHOTOVOLTAÏQUE D'ILE-DE-FRANCE



2016

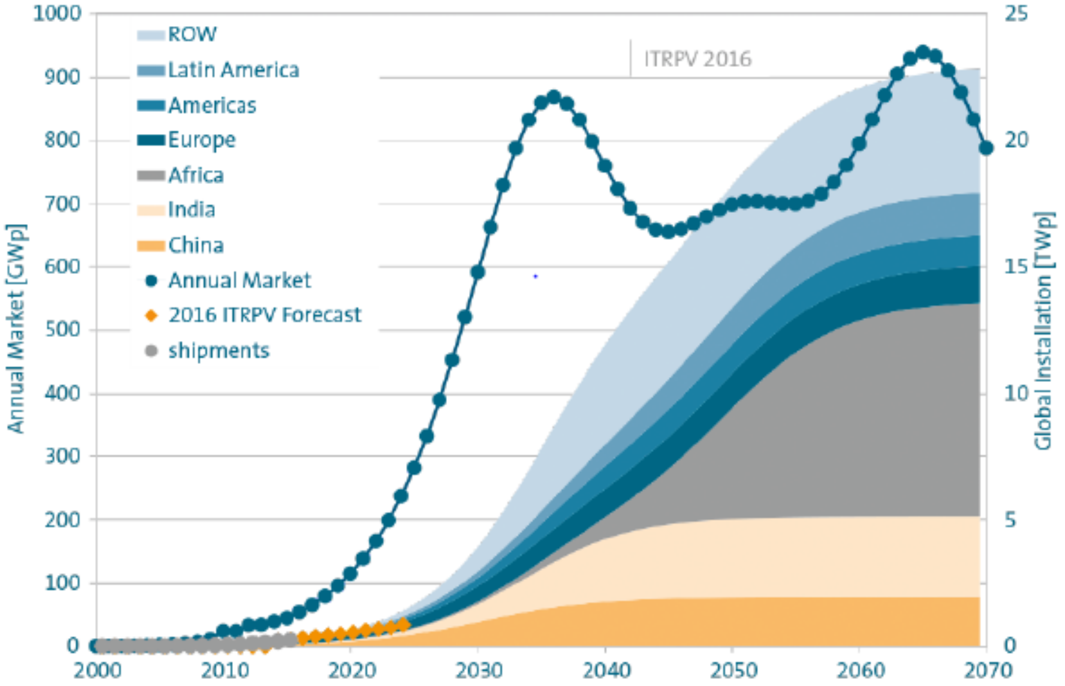


Fig. 48: Cumulative installed module power calculated with a logistic growth approximation for Scenario 2, assuming 23 TWp installed PV module power in 2070 (see Table 2).

confidentiel

Photovoltaics in the Energy Transition (II)

IPVF

2017

nature energy

PERSPECTIVE

PUBLISHED: 25 AUGUST 2017 | VOLUME: 2 | ARTICLE NUMBER: 17140

The underestimated potential of solar energy to mitigate climate change

Felix Creutzig[1,2*], Peter Agoston[1], Jan Christoph Goldschmidt[3], Gunnar Luderer[4], Gregory Nemet[1,5] and Robert C. Pietzcker[4]

The Intergovernmental Panel on Climate Change's fifth assessment report emphasizes the importance of bioenergy and carbon capture and storage for achieving climate goals, but it does not identify solar energy as a strategically important technology option. That is surprising given the strong growth, large resource, and low environmental footprint of photovoltaics (PV). Here we explore how models have consistently underestimated PV deployment and identify the reasons for underlying bias in models. Our analysis reveals that rapid technological learning and technology-specific policy support were crucial to PV deployment in the past, but that future success will depend on adequate financing instruments and the management of system integration. We propose that with coordinated advances in multiple components of the energy system, PV could supply 30–50% of electricity in competitive markets.

Photovoltaics in the Energy Transition (I)

C. R. Physique 18 (2017) 381–390

Contents lists available at ScienceDirect

Comptes Rendus Physique

www.sciencedirect.com

Demain l'énergie – Séminaire Daniel-Dautreppe, Grenoble, France, 2016

The new paradigm of photovoltaics: From powering satellites to powering humanity

Le nouveau paradigme de l'énergie solaire photovoltaïque : de l'alimentation électrique des satellites à celle de l'humanité

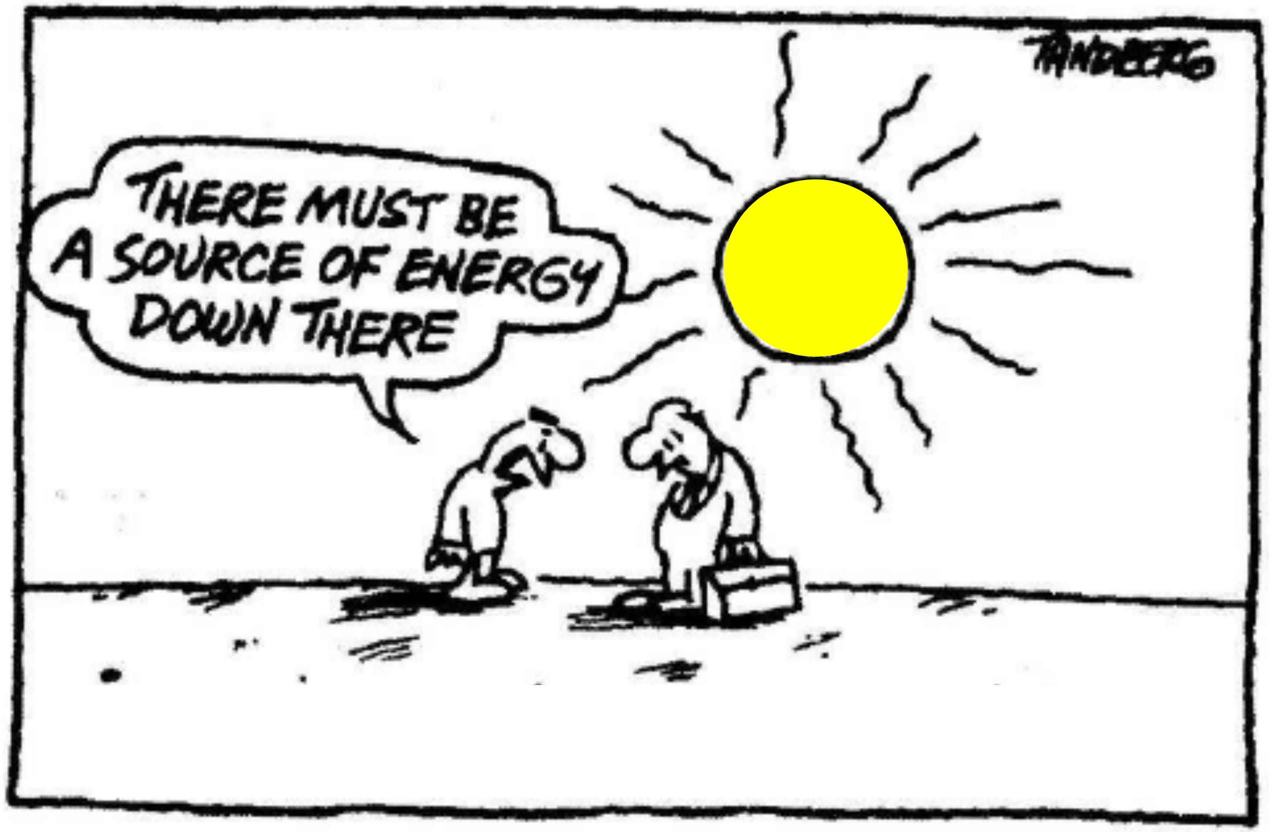
OPEN ACCESS

Daniel Lincot

CNRS, Institut photovoltaïque d'Île-de-France (IPVF), 30, route 128, 91120 Palaiseau, France

Thanks for your attention

Atacama, Chile 2018



Conclusions : Photovoltaics is becoming a pillar of the energy transition

The perspective of development are immense

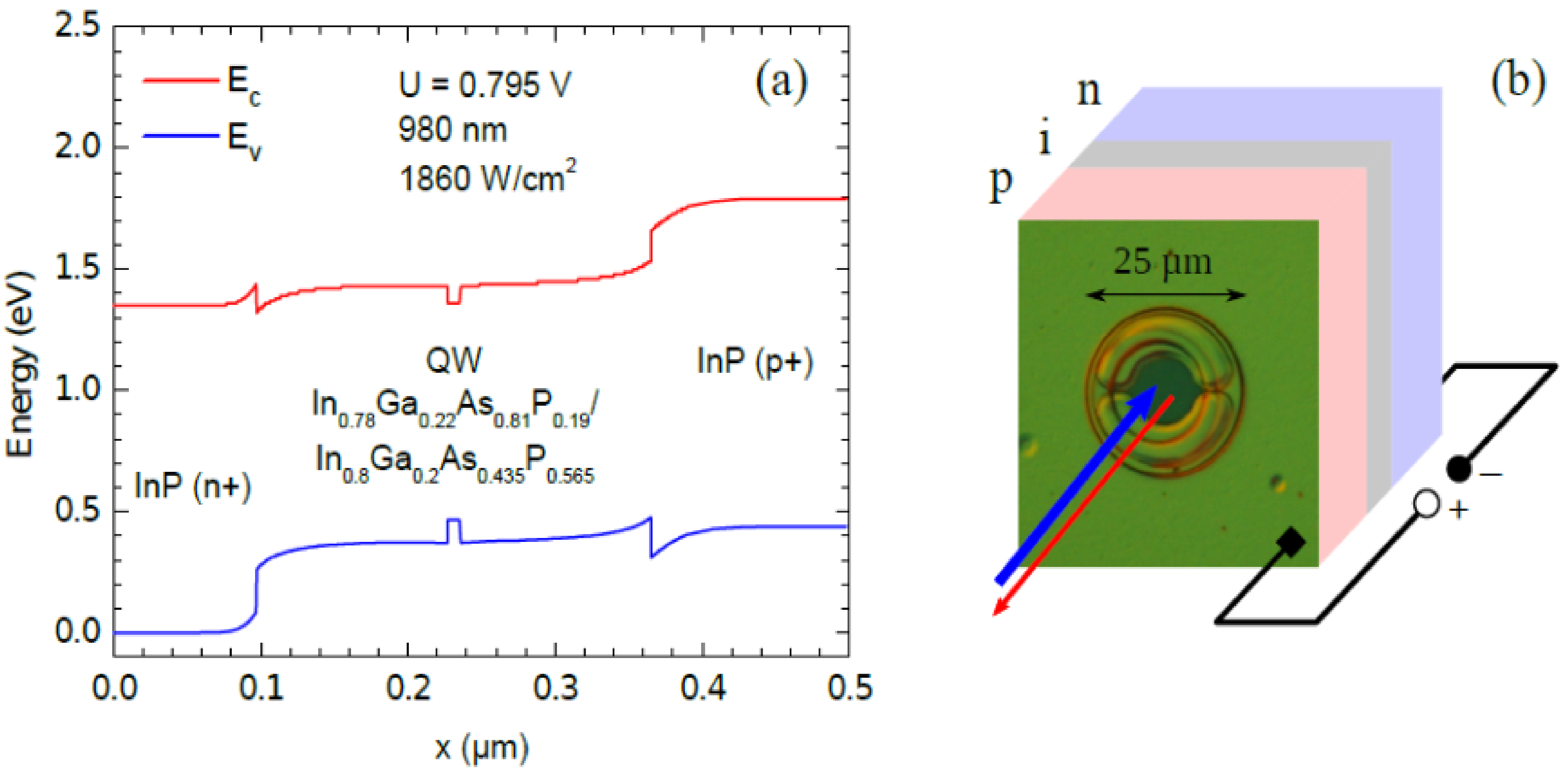
No energy ressource limitation,
Huge margin of scientific and technological improvements
High Cost reduction perspectives
Diversity of applications and markets

The role of R&D will not decrease but increase in a complex environment

-Fast evolution of the field
-Strong competition between the technologies and markets
- Relation between innovative and established technologies (lock in)

Increased synergies with connected sectors

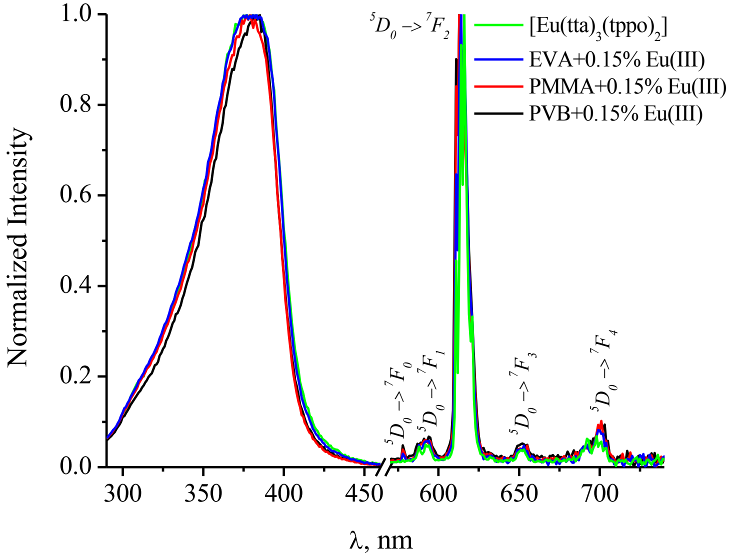
- Electrical Mobility
- Storage
- Chemistry (hydrogen, solar fuels)
- digital technologies
- Houses, buildings, cities, agriculture…society

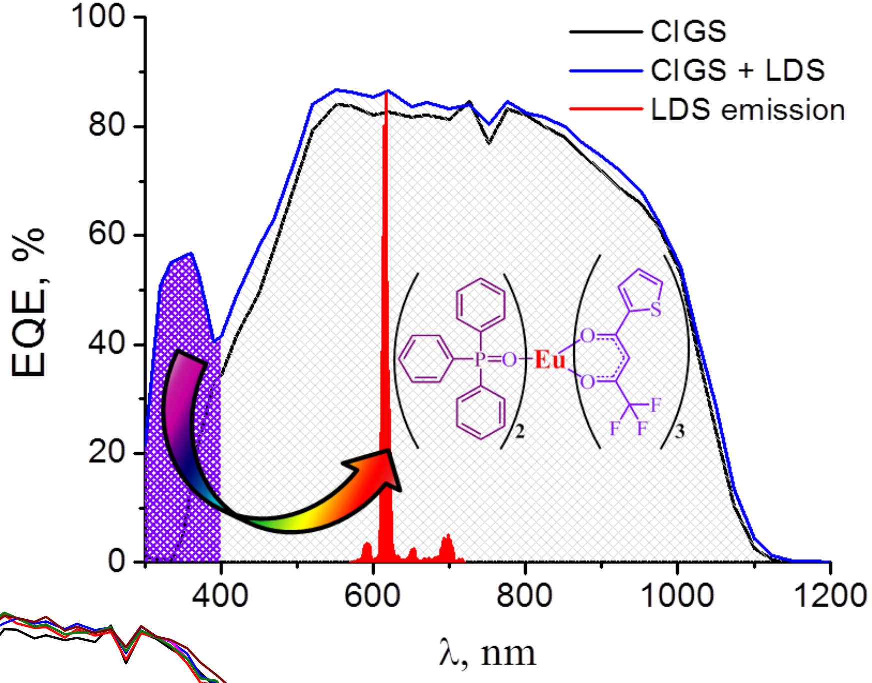


2.5
2.0
1.5
1.0
0.5
0.0
Energy (eV)
E_c
E_v
U = 0.795 V
980 nm
1860 W/cm^2
(a)
QW
$In_{0.78}Ga_{0.22}As_{0.81}P_{0.19}$/
$In_{0.8}Ga_{0.2}As_{0.435}P_{0.565}$
InP (n+)
InP (p+)
0.0
0.1
0.2
0.3
0.4
0.5
x (µm)
n
i
p
(b)
25 µm
–
+

Photon Conversion : Exemple of Down Conversion studies

Exemple de conversion UV→ Visible : Down conversion

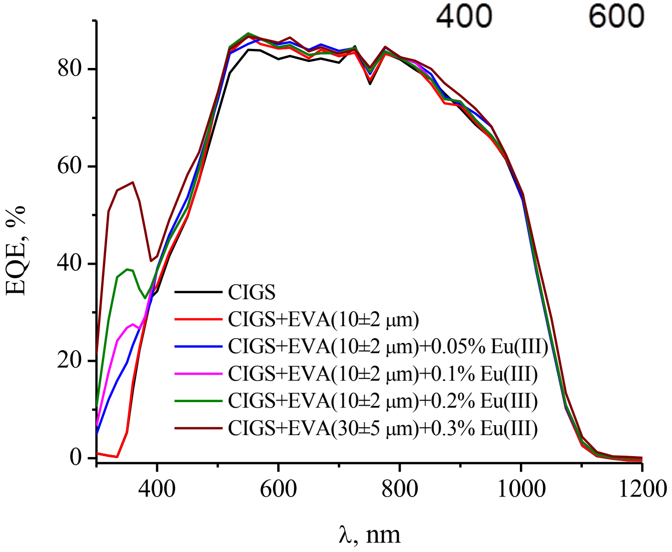




Enhancement of CIGS solar cells using [Eu(tta)$_3$(tppo)$_2$] complex

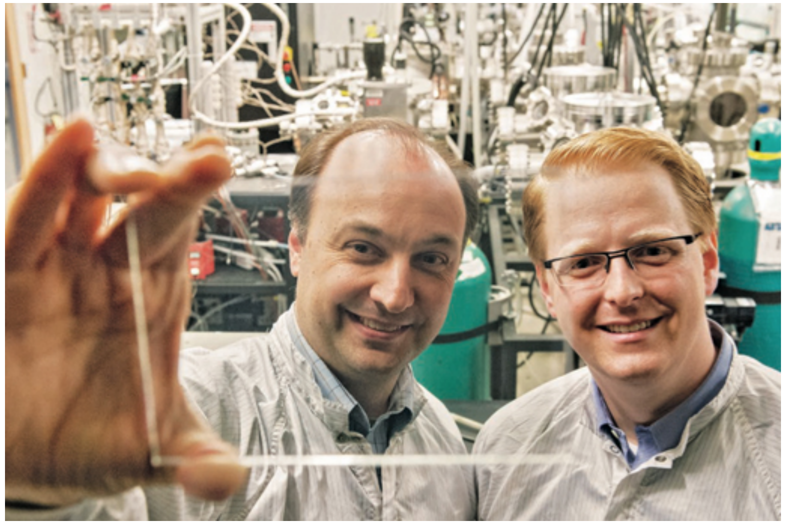
Anatolie Gavriluta,[1,2,3] Thomas Fix,[2] Aline Nonat,[3] Myriam Paire,[4,1] Abdelilah Slaoui,[2] Loïc J. Charbonnière,[3] Jean-François Guillemoles[5,1]

Solar Energy Materials Février 2017



Modules Photovoltaïques blancs et colorés
2015 –EPFL Suisse

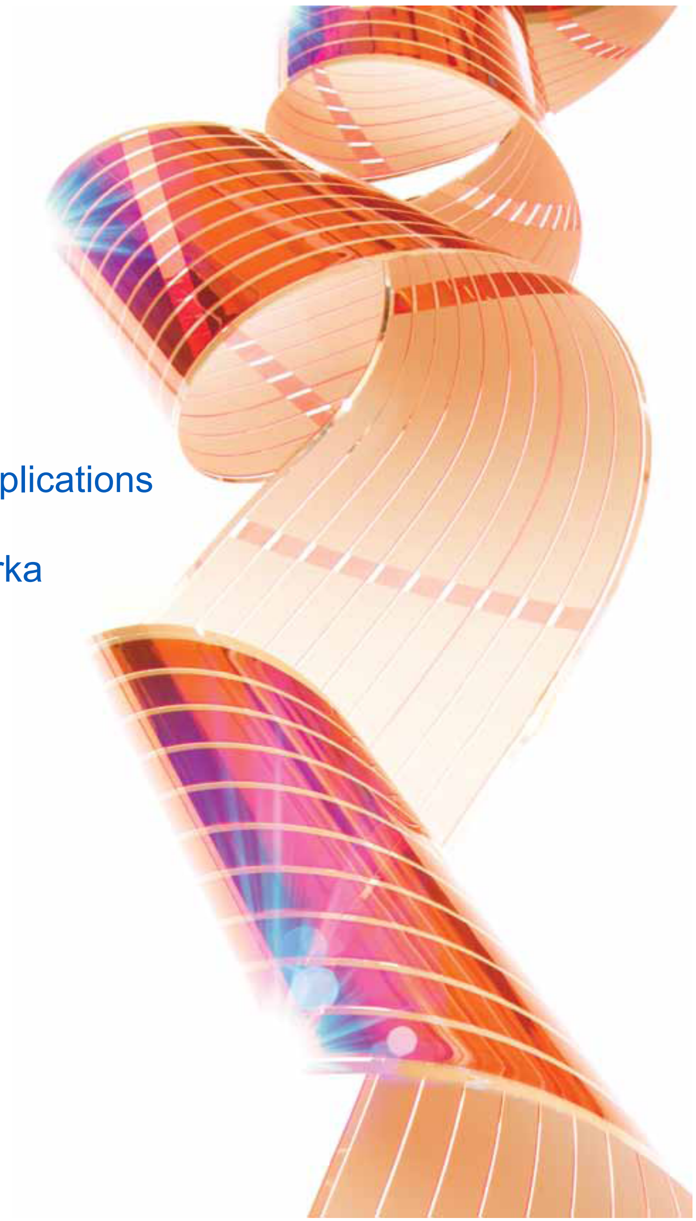
Modules Photovoltaïques Transparents
2015 –MIT



Le Photovoltaique plastique (marchés de niche) Cell. 8-9%, Mod. 3%

Exemple of Organic PV applications

Source : Web site of Konarka



D. Lincot , Executive master Ecole Polytechnique, 6th february 2018