



anfchimsol2015 : Action Nationale de Formation : Chimie du solide CAEN

23-25 nov. 2015 CAEN (France)



Conférence des Nations unies
sur les changements climatiques

COP21/CMP11

DU 30 NOVEMBRE AU 11 DÉCEMBRE 2015 À PARIS

Nouveaux Matériaux pour la conversion photovoltaïque

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I N S T I T U T
P H O T O V O L T A I Q U E
D ' I L E - D E - F R A N C E



INSTITUTE OF R&D ON PHOTOVOLTAIC ENERGY



advancing the frontiers

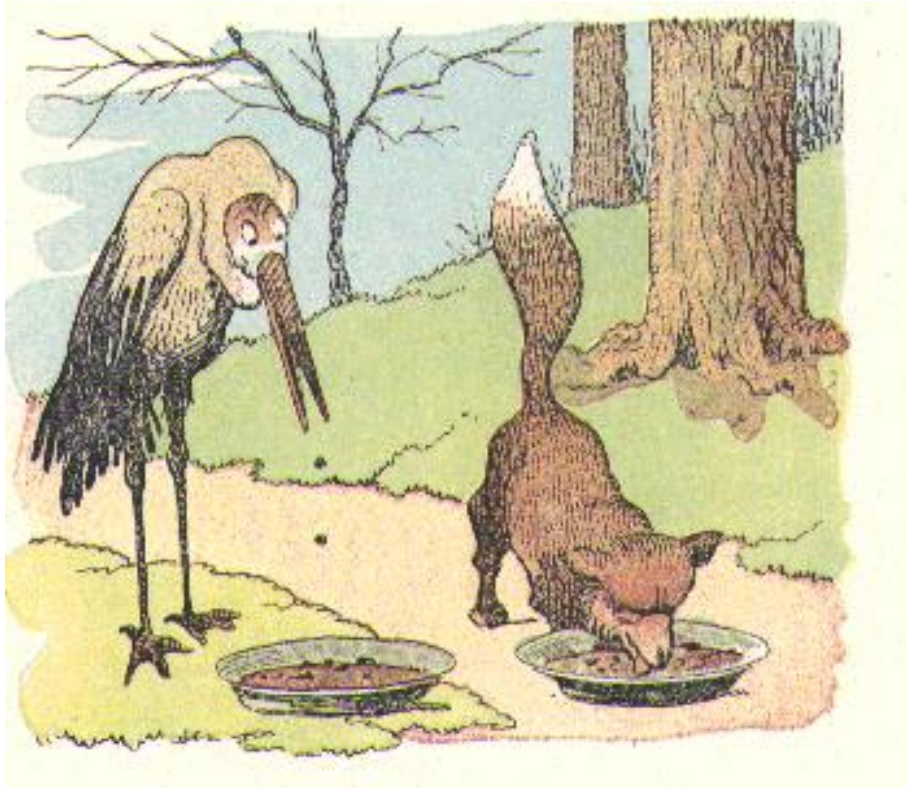


LEADING THE ENERGY CHANGE



ParisTech

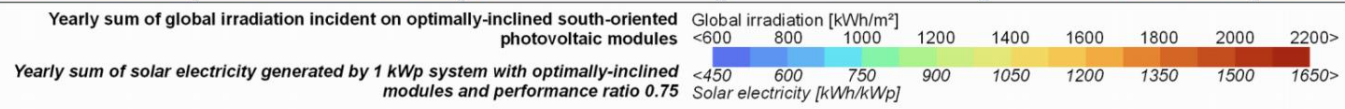
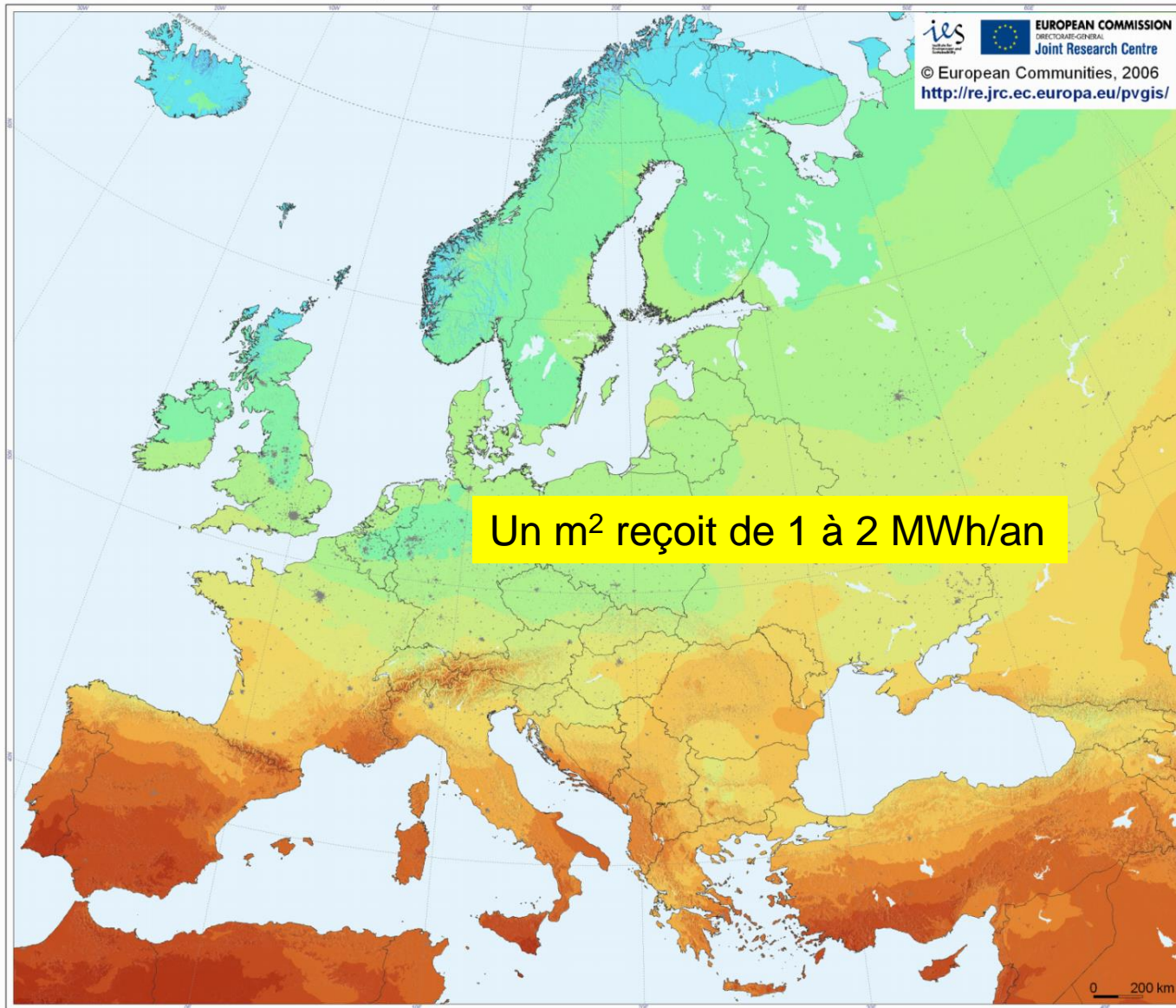
Le renard et la Cigogne : lorsque une fable de Jean de la Fontaine (1621-1695) nous parle aussi d'énergie et de la COP21



Source : fergant.clg61.ac-caen.fr

- 1- Avoir une source d'énergie
- 2- Développer des technologies adaptées pour l'utiliser : Savoir s'adapter !

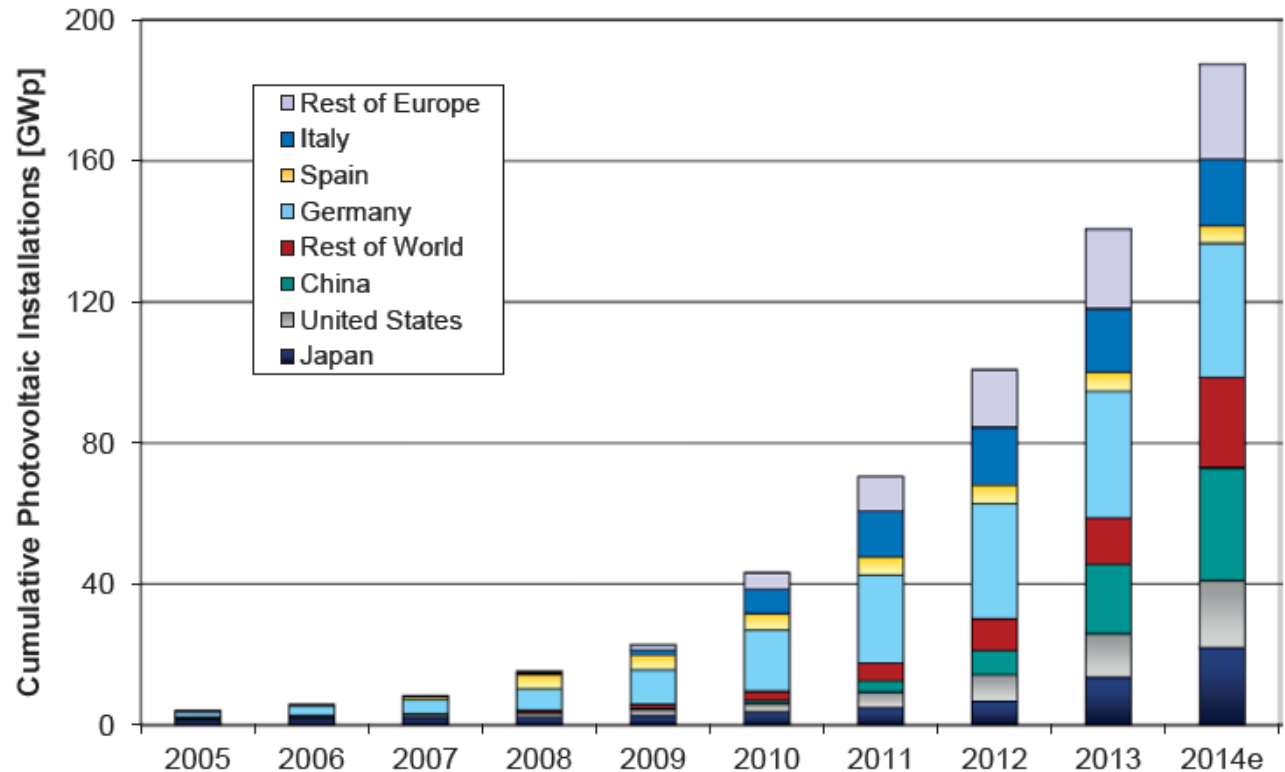
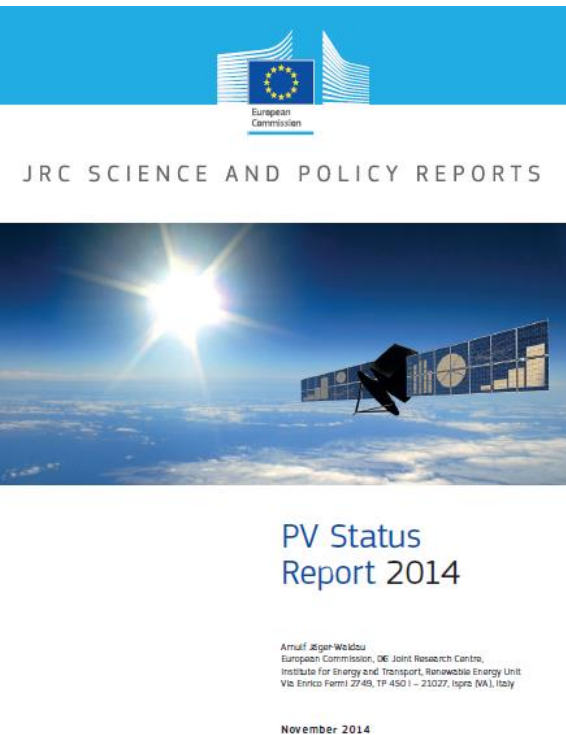
Photovoltaic Solar Electricity Potential in European Countries



L'énergie photovoltaïque dans le secteur de l'énergie





















2000 : Début des politiques clés de soutien au développement du photovoltaïque

2005-2015 : Le photovoltaïque passe de l'épaisseur du trait à 1% de la production mondiale d'électricité



2015 : 200 GW (1% de la production électrique mondiale)
 Projection 2020 : 500 GW
 Projection 2050 : 4,5 TW , 16% de l'électricité mondiale (AIE)

TABLE 1: TOP 10 COUNTRIES FOR INSTALLATIONS AND TOTAL INSTALLED CAPACITY IN 2014

	TOP 10 COUNTRIES IN 2014 FOR ANNUAL INSTALLED CAPACITY			TOP 10 COUNTRIES IN 2014 FOR CUMULATIVE INSTALLED CAPACITY		
1 st		China	10,6 GW		Germany	38,2 GW
2 nd		Japan	9,7 GW		China	28,1 GW
3 rd		USA	6,2 GW		Japan	23,3 GW
4 th		UK	2,3 GW		Italy	18,5 GW
5 th		Germany	1,9 GW		USA	18,3 GW
6 th		France	0,9 GW		France	5,7 GW
7 th		Australia	0,9 GW		Spain	5,4 GW
8 th		Korea	0,9 GW		UK	5,1 GW
9 th		South Africa	0,8 GW		Australia	4,1 GW
10 th		India	0,6 GW		Belgium	3,1 GW

NUMBERS HAVE BEEN ROUNDED

Source: IEA PVPS

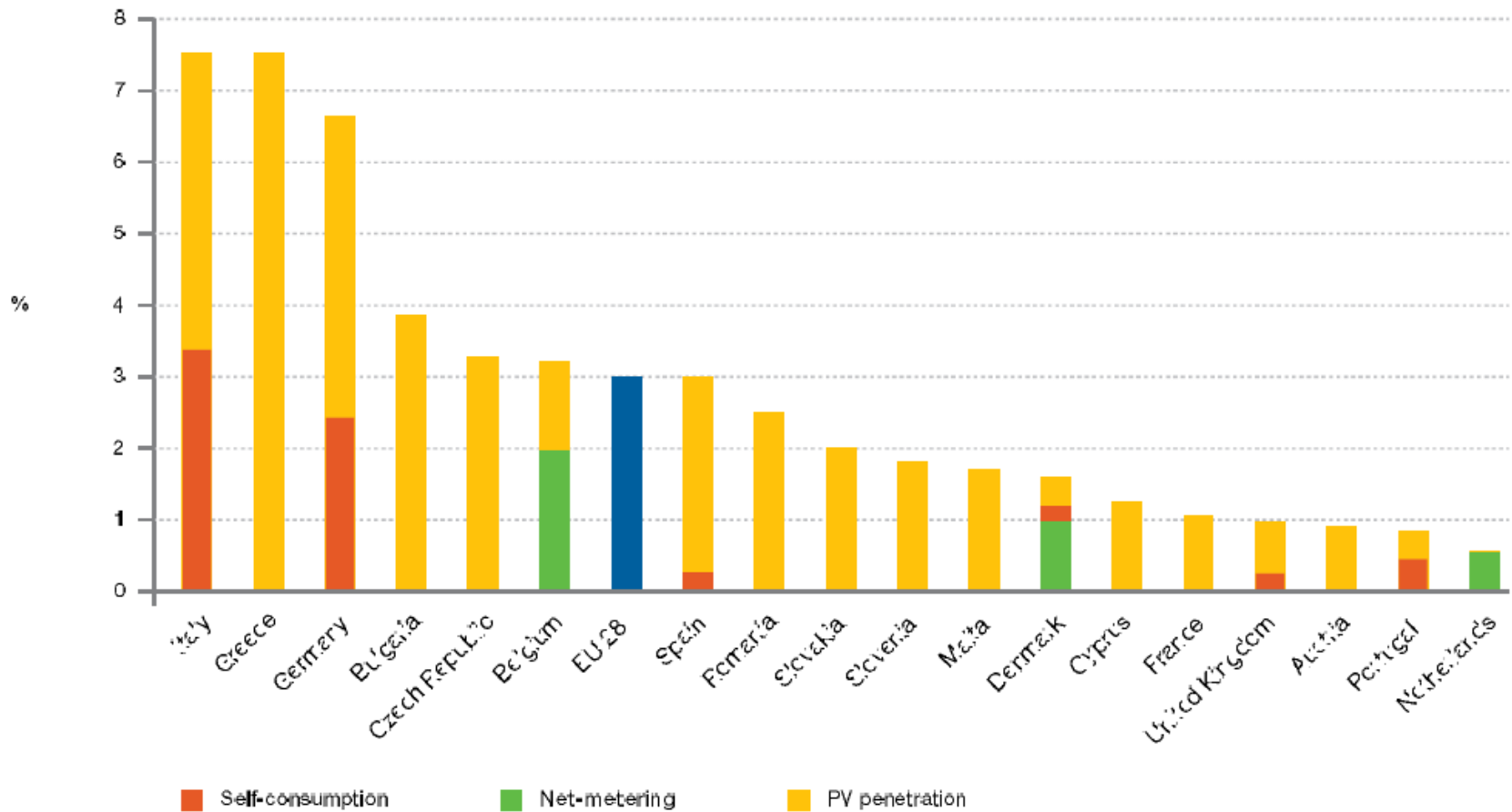


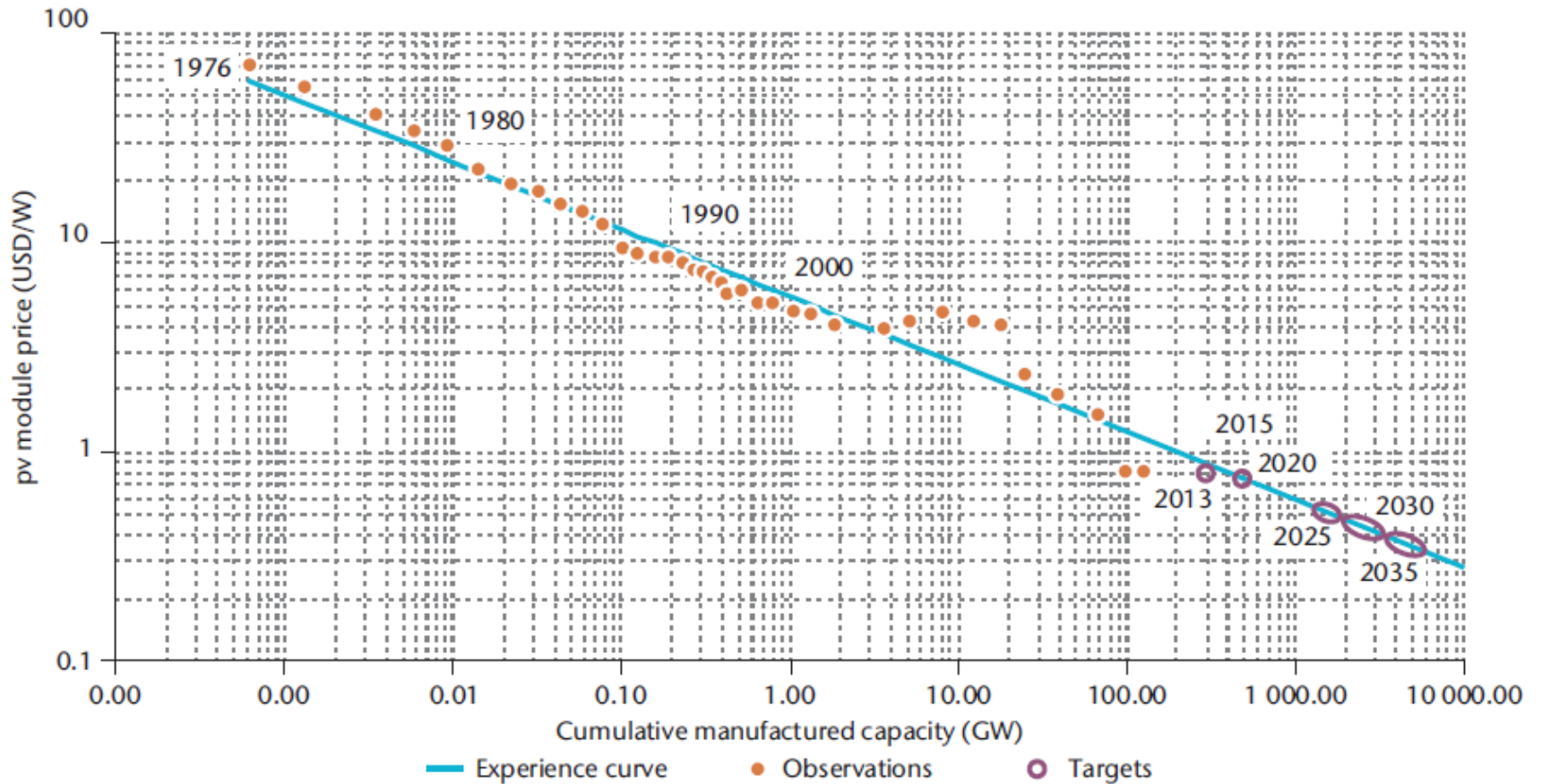
Figure 28 - PV contribution to the electricity demand in the EU 28 in 2013

Source :European Photovoltaic Industrial Association 2014

Moteur du développement du
photovoltaïque :

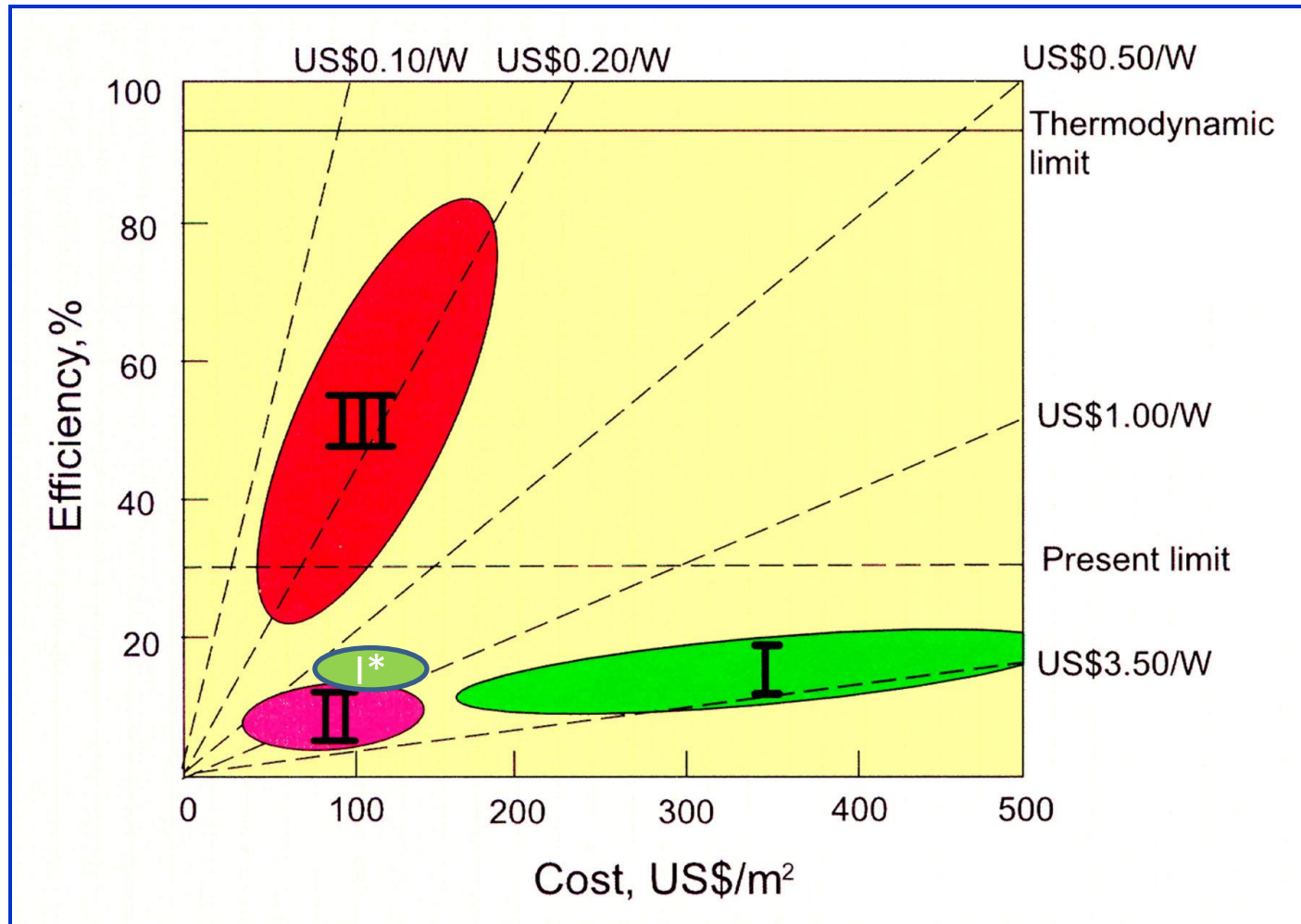
l'abaissement du coût de l'électricité
photovoltaïque

Courbe d'expérience des prix des modules photovoltaïques (source AIE)



Notes: Orange dots indicate past module prices; purple dots are expectations. The oval dots correspond to the deployment starting in 2025, comparing the 2DS (left end of oval) and 2DS hi-Ren (right end).

Strategic roadmap for photovoltaic generators



I- Crystalline Silicon (2008)

I*- **Crystalline silicon (2015)**

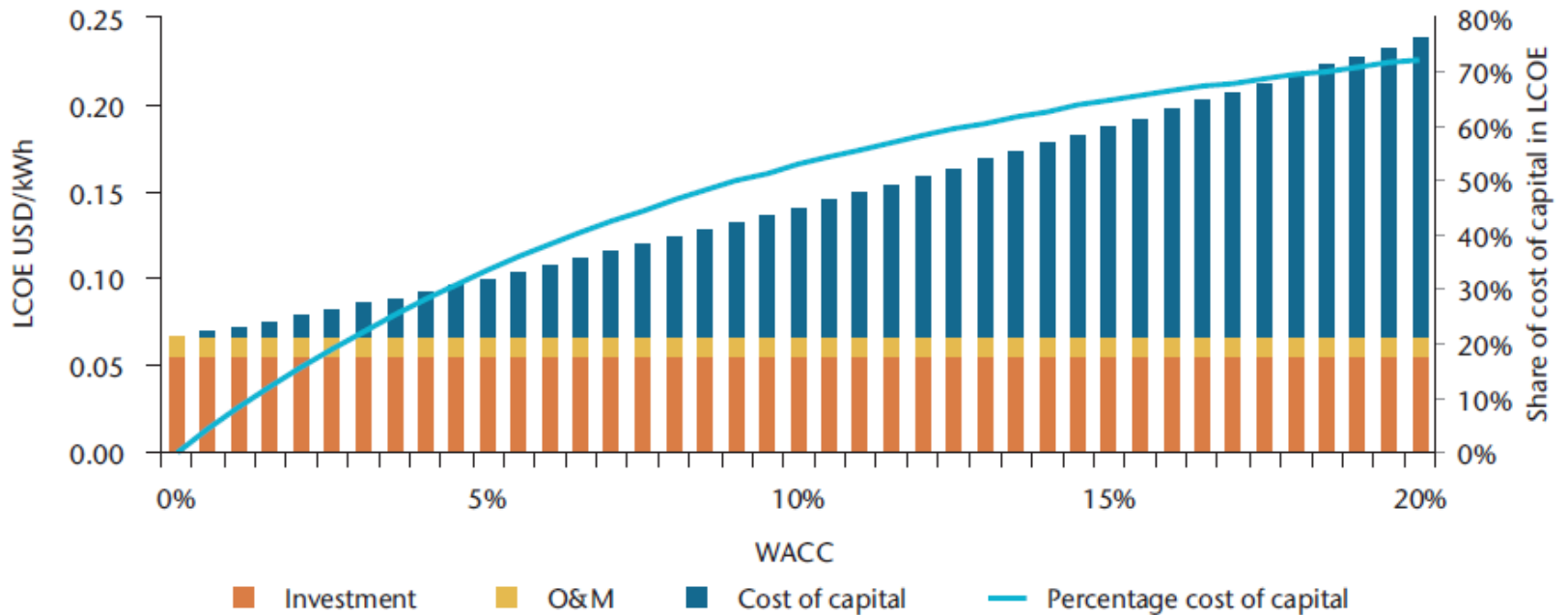
II- Thin Films

III- Multijunctions and new concepts

Cout de production de l'électricité PV

- Ressource : 1,3 MWh par m² et par an
- Production du module
 - Rendement du module : 15% soit 150 W
 - Production 200 kWh/an soit 4 MWh sur 20 ans
- Cout de l'électricité
 - Cout actuel du module : 0,6 \$/W soit 90\$ pour 150 W
 - LCOE (module) = $90/4000 = 0,022\$/\text{kWh}$
 - LCOE (total) = LCOE(M)+LCOE(Système)+autres : **<0,1 \$/kWh**
- Futur LCOE(M): 1 c\$/kWh ? Pour 0,3\$/W

Effet du financement sur le prix de l'électricité photovoltaïque (Source AIE)



Notes: This example is based on output of 1 360 kWh/kW/y, investment costs of USD 1 500/W, annual operations and maintenance (O&M) of 1% of investment, project lifetime of 20 years, and residual value of 0.

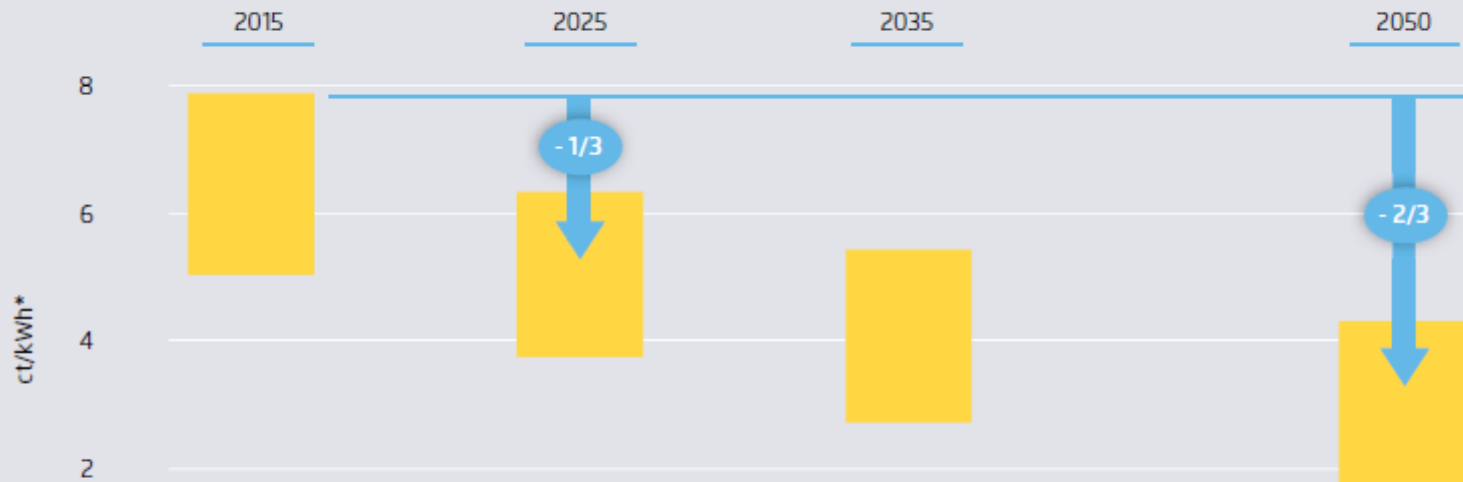
Current and Future Cost of Photovoltaics

Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems

STUDY

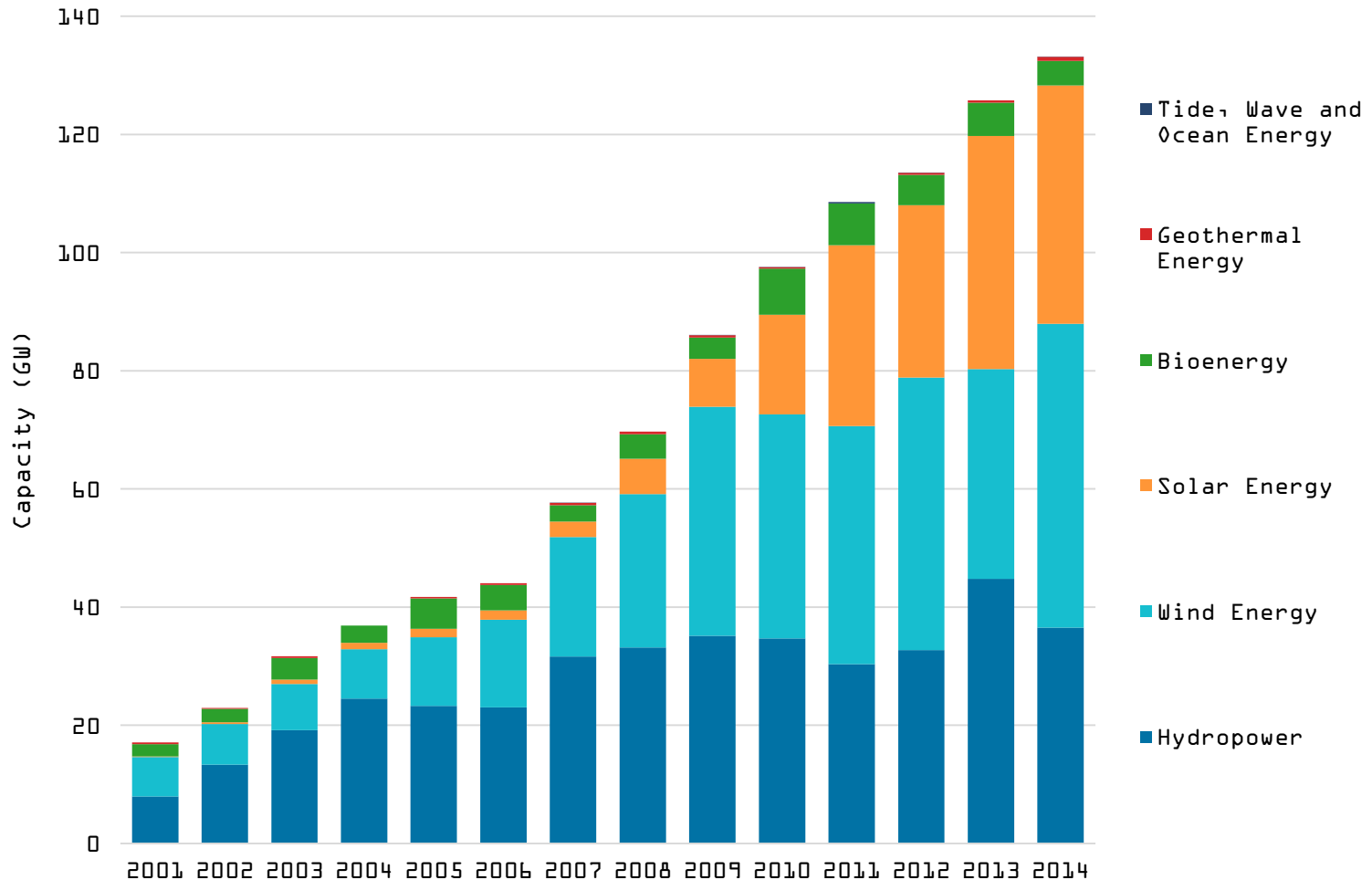
Agora
Energiewende
Fraunhofer
ISE

Cost of electricity from new solar power plants in Southern and Central Europe

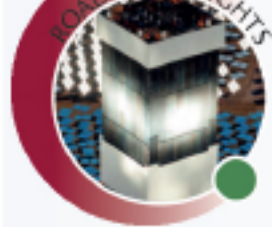


* Real values in EUR 2014; bandwidth represent different scenarios of market, technology and cost development, as well as power plant location between south of Germany (1190 kWh/kWp/y) and south of Spain (1680 kWh/kWp/y); assuming 5% (real) weighted average cost of capital.

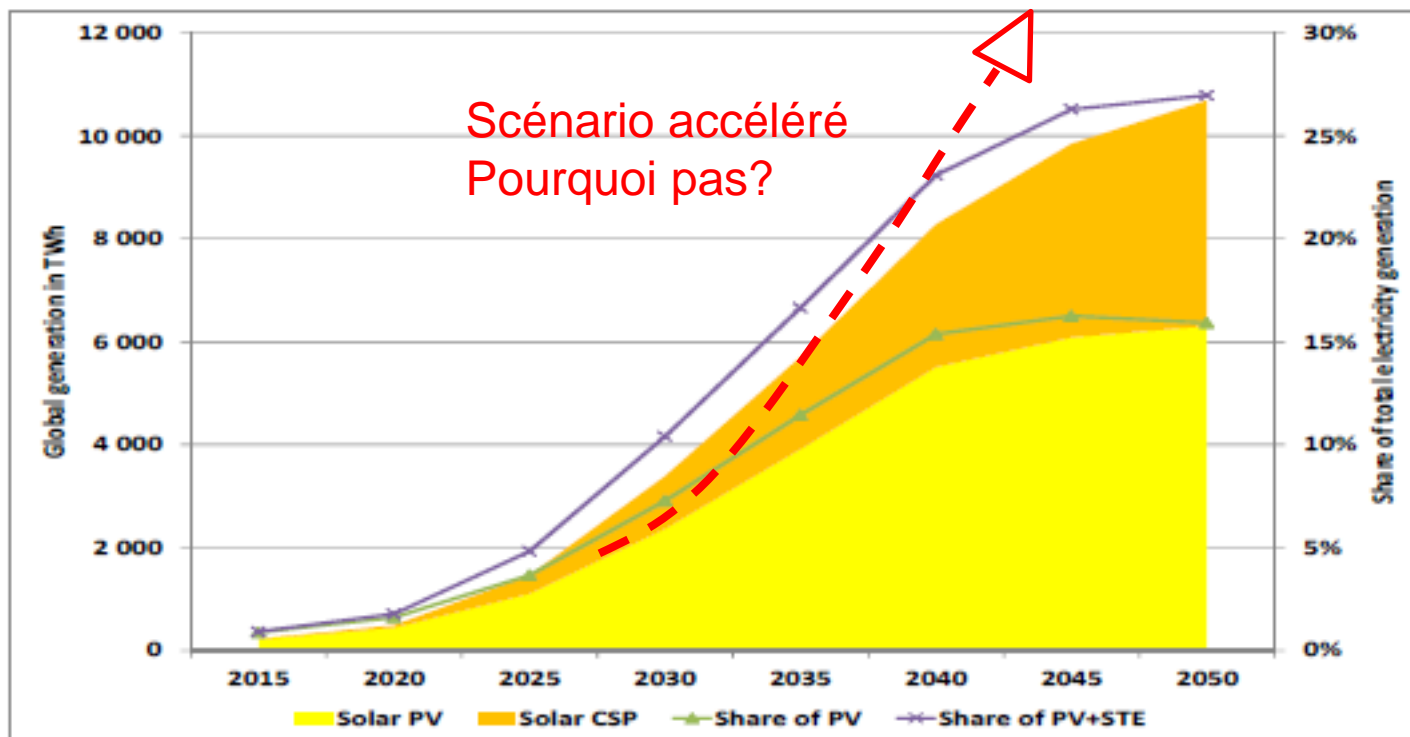
Installed Renewable Power Capacity - Net additions



2014 was a record year for the renewable power sector with 133 GW of net additions. More than 100 GW of new renewable power capacity have been added every year since 2011



New roadmap vision for solar electricity: PV + STE



Together, PV and STE could become the largest source of electricity worldwide before 2050

DES ROUTES SOLAIRES ?



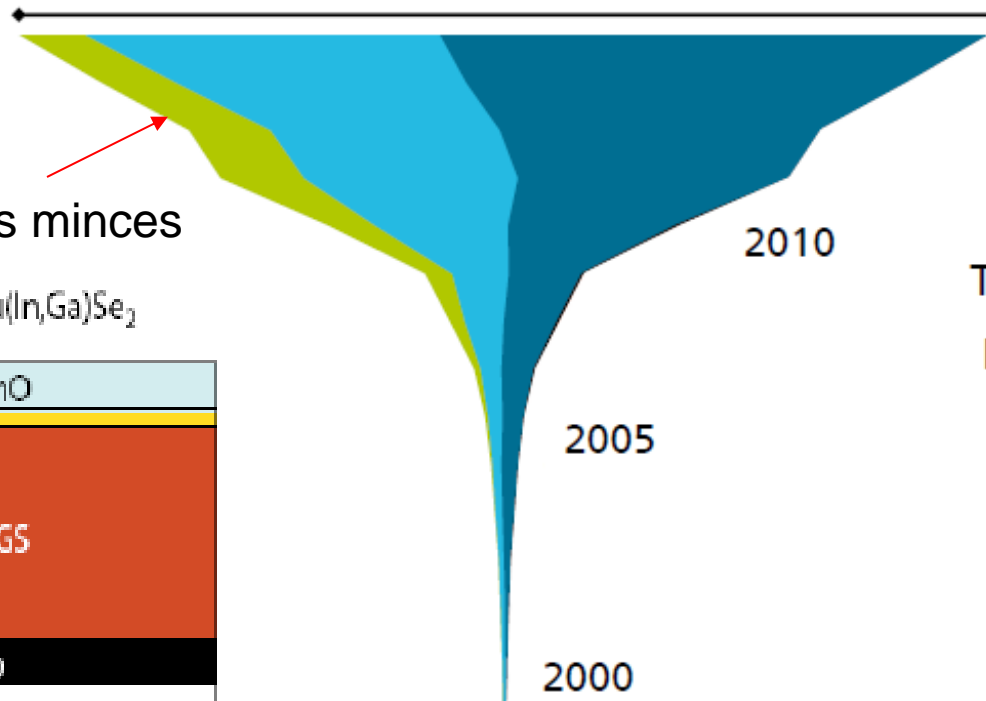
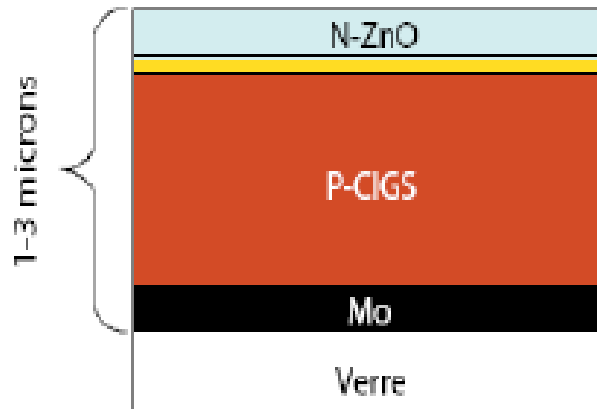
Le revêtement est composé de cellules photovoltaïques recouvertes d'un alliage transparent afin de résister au passage des poids lourds. - © Joachim Bertrand / COLAS **Innovation Bouygues/colas-INES**

Les différentes filières photovoltaïques actuelles

About 47.5* GWp PV module production in 2014

Cellule en couches minces

Cellule au $\text{Cu}(\text{In,Ga})\text{Se}_2$



Thin film		10%
Mono-Si		90%
Multi-Si		

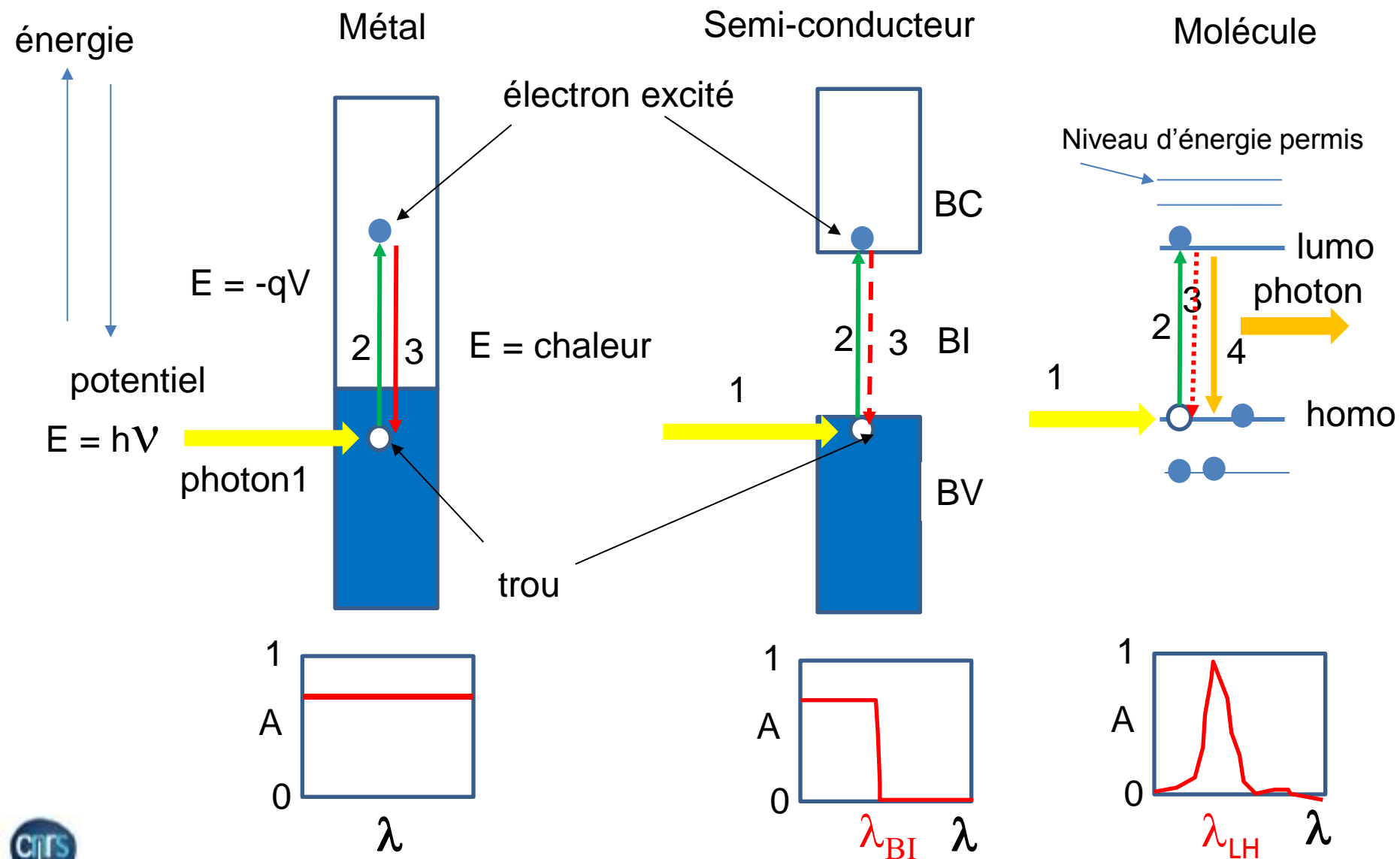
Data: from 2000 to 2010: Navigant; from 2011: IHS (Mono-/Multi- proportion: Paula Mints). Graph: PSE AG 2015

Mécanismes fondamentaux de la conversion photovoltaïque

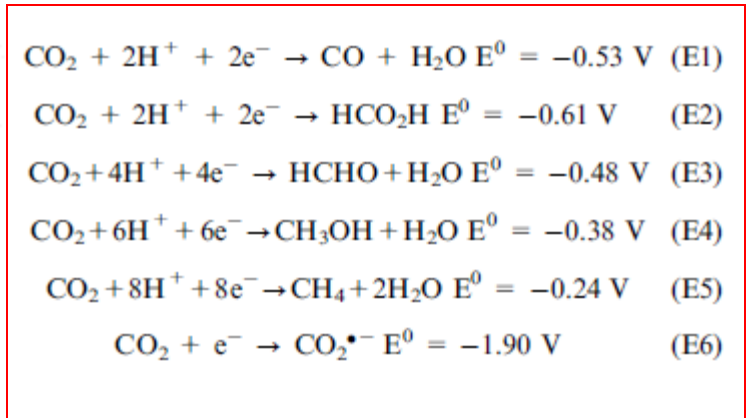
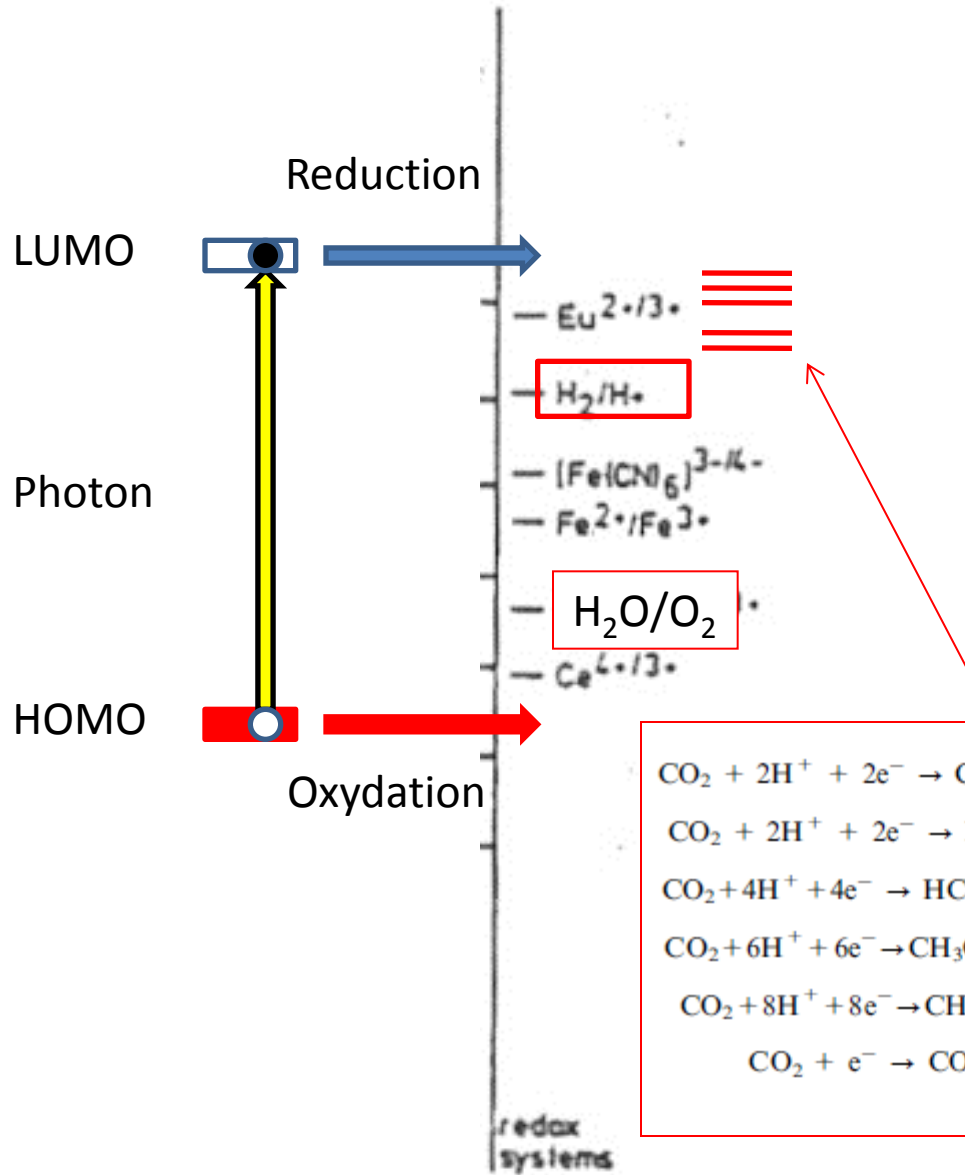
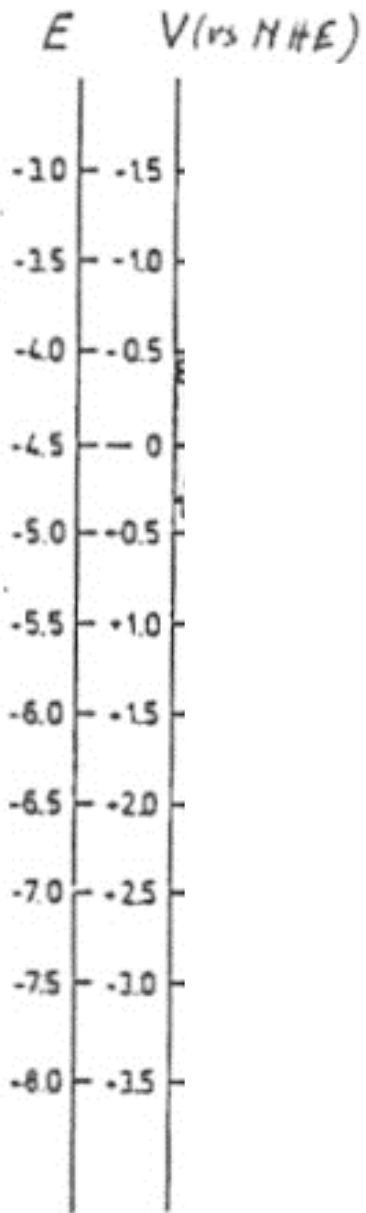
Énergie d'un photon : $E = h\nu = hc/\lambda$

L'interaction lumière-matière

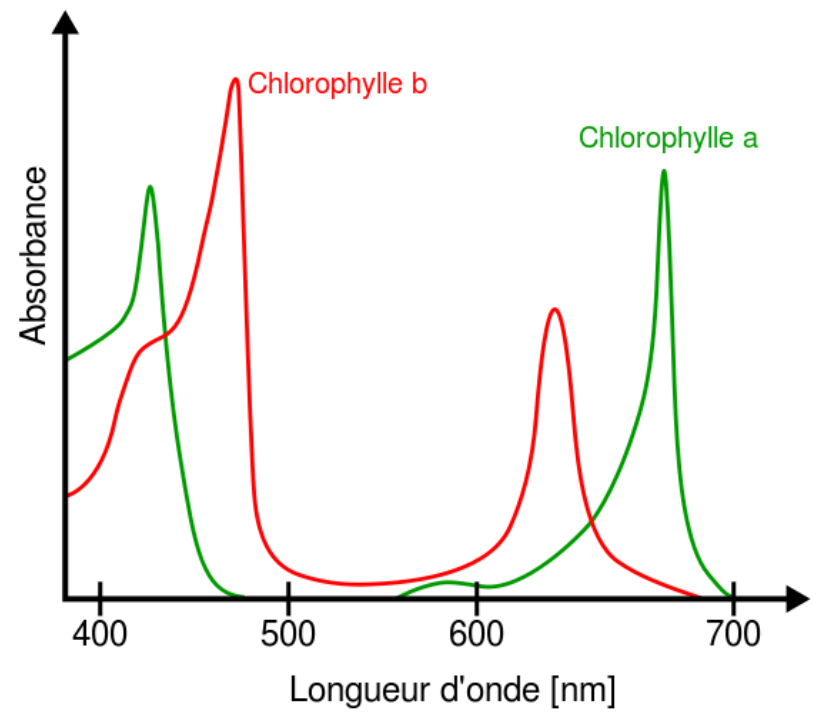
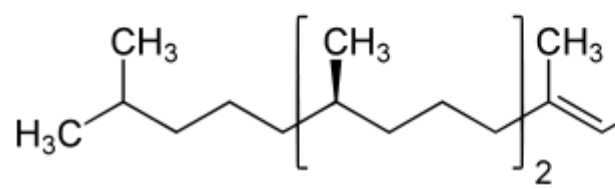
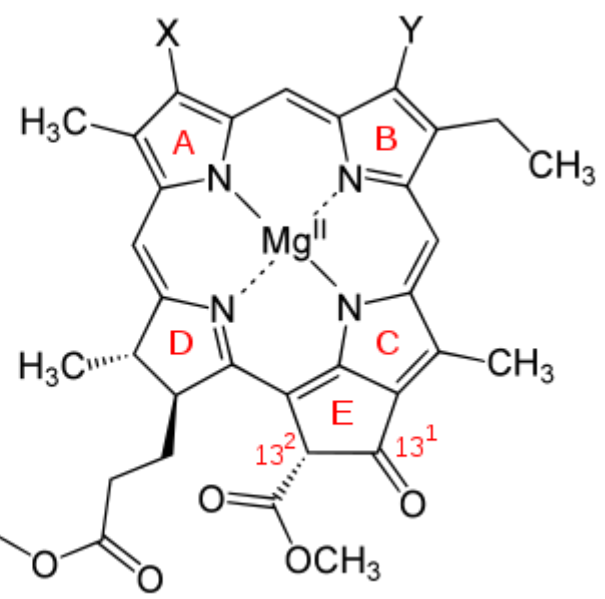
Un dialogue énergétique permanent entre et Photon-Electron

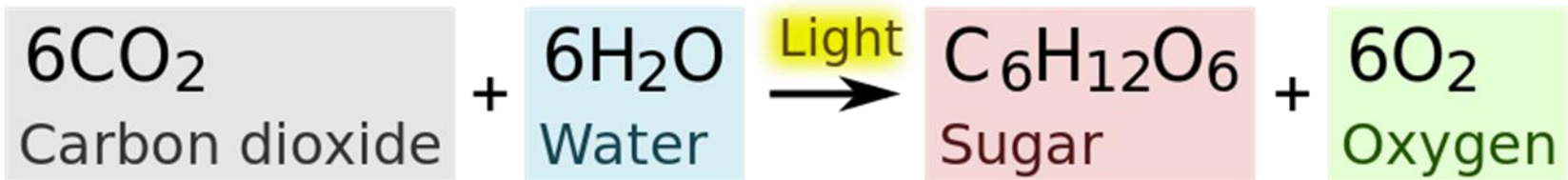
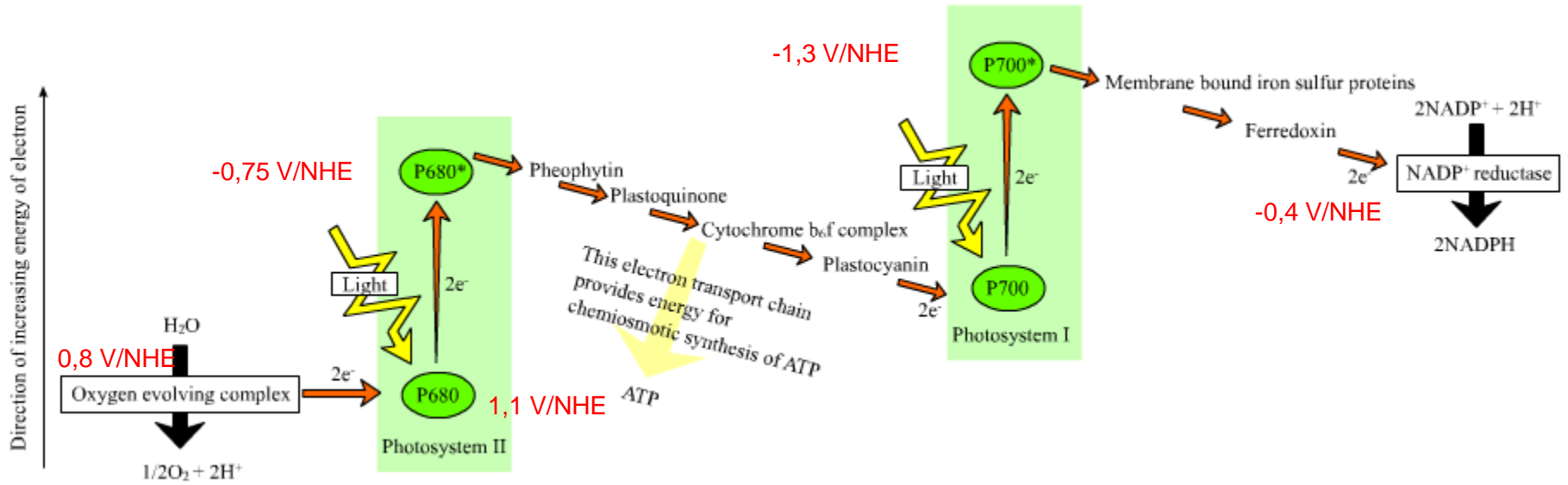


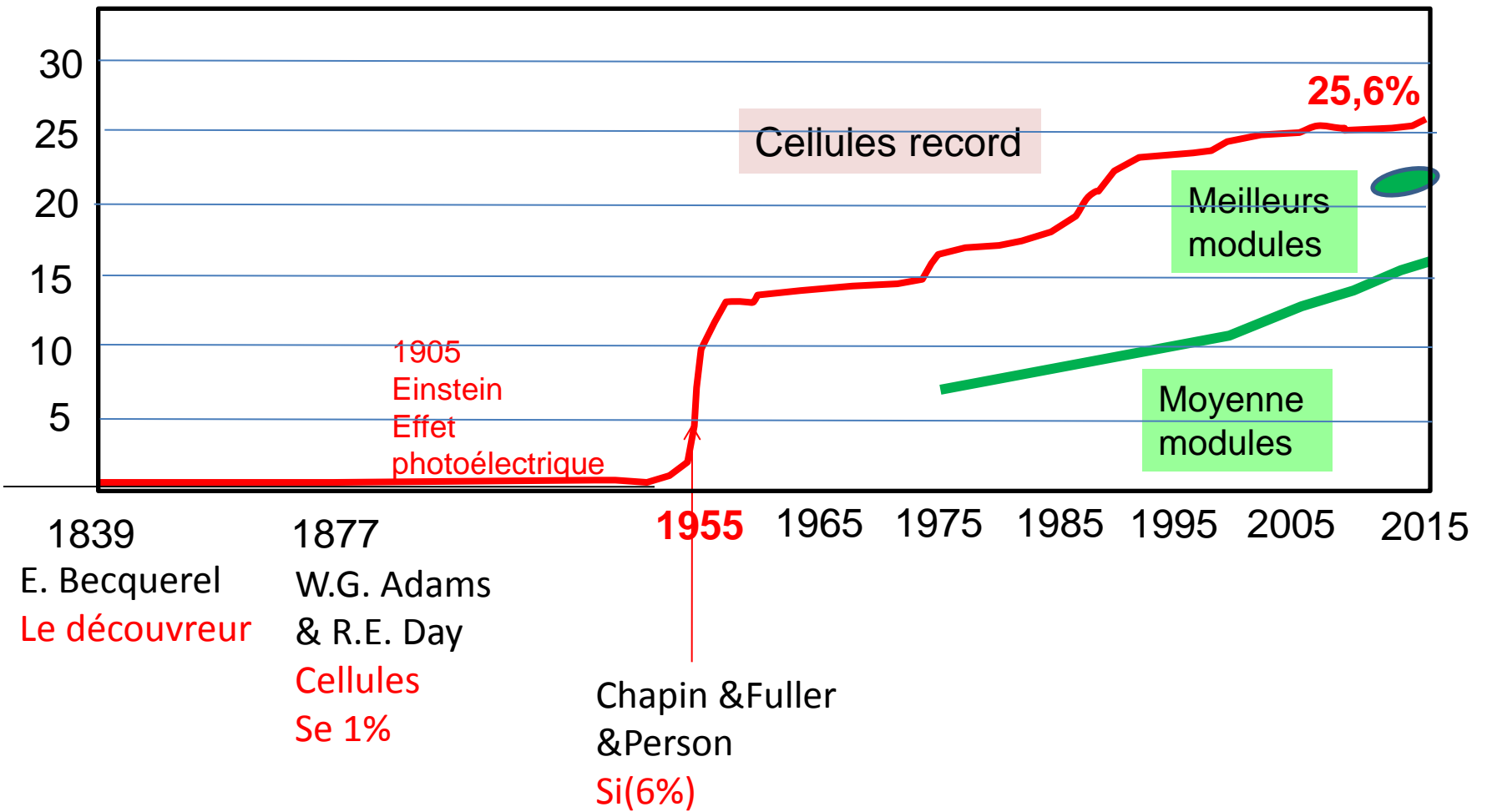
Photosynthèse : des cellules photovoltaïques couplées à des transformations électrochimiques à l'échelle moléculaire



- a** X: CH=CH₂ Y: CH₃
- b** X: CH=CH₂ Y: CHO
- d** X: CHO Y: CH₃



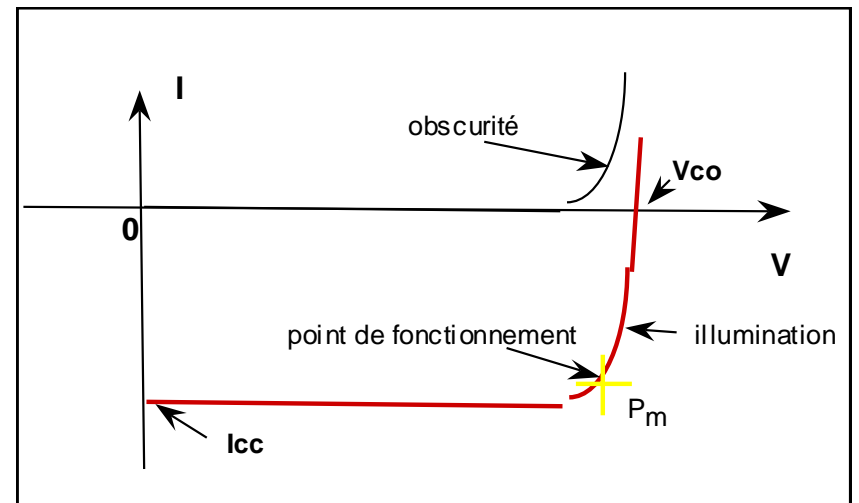
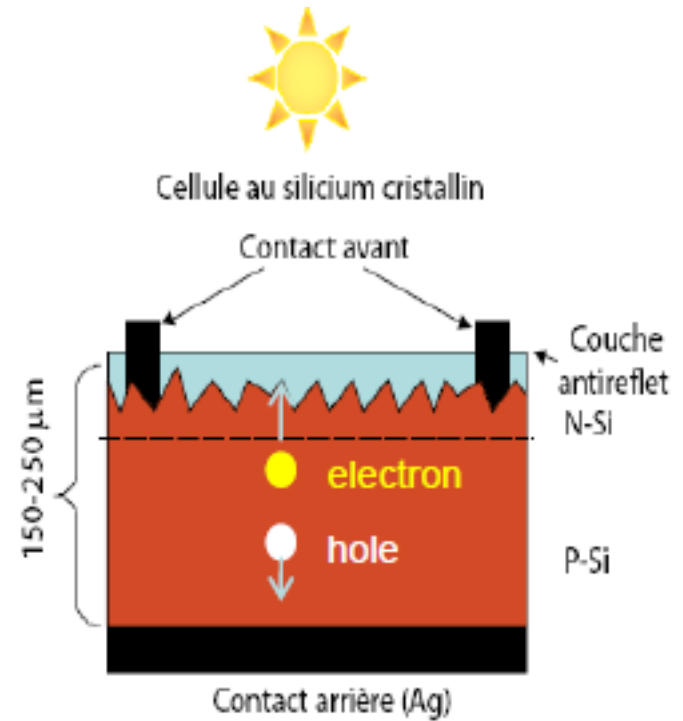
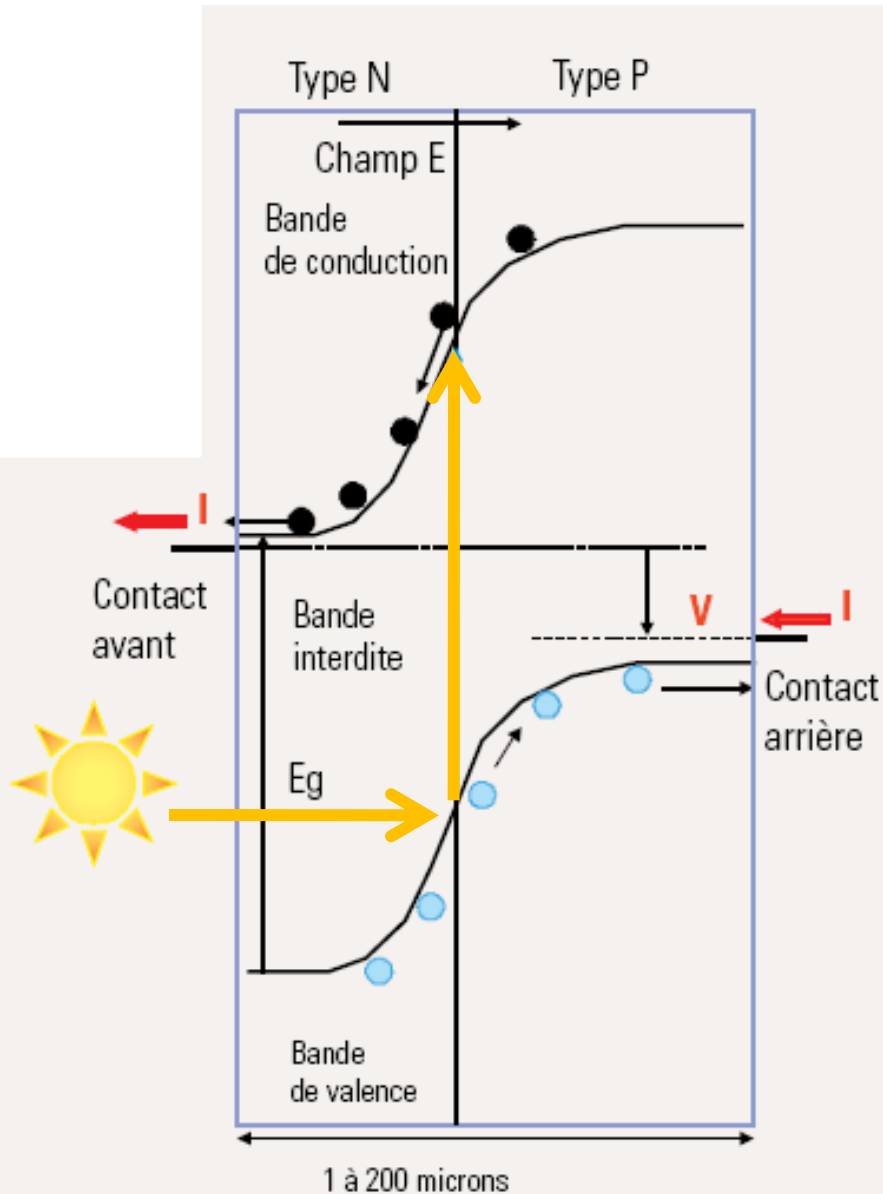




Ref : M. de Wild Scholten « Energy pay back time and carbon footprint of commercial PV systems »
 Solar Energy Materials and Solar Cells, 119(2013)296

1954 Naissance des cellules PV modernes au silicium

Si dopé P (B) Si dopé N (P)



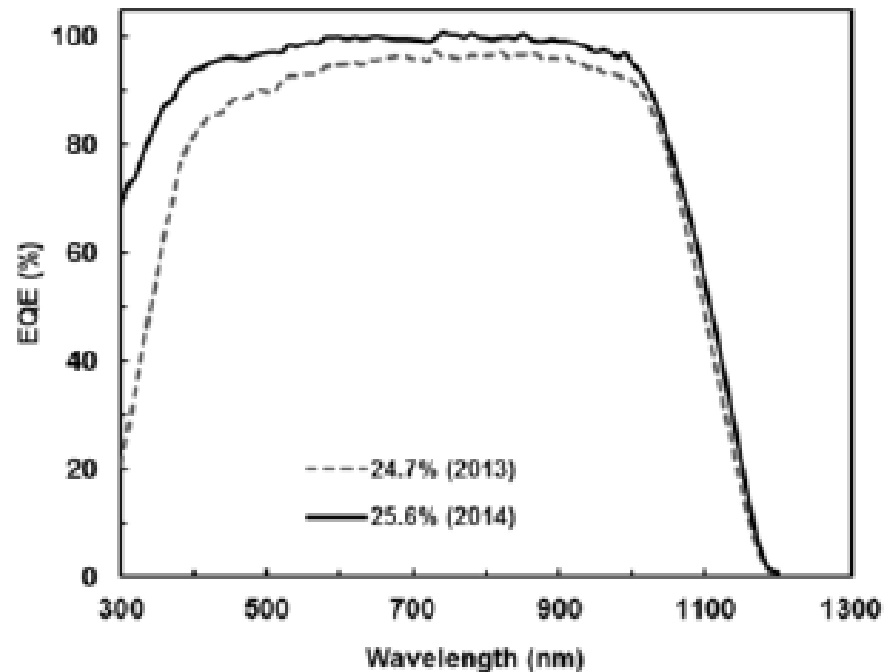
$$I = I_0 [\exp (qV/nkT) - 1] - I_L$$

Achievement of More Than 25% Conversion Efficiency With Crystalline Silicon Heterojunction Solar Cell

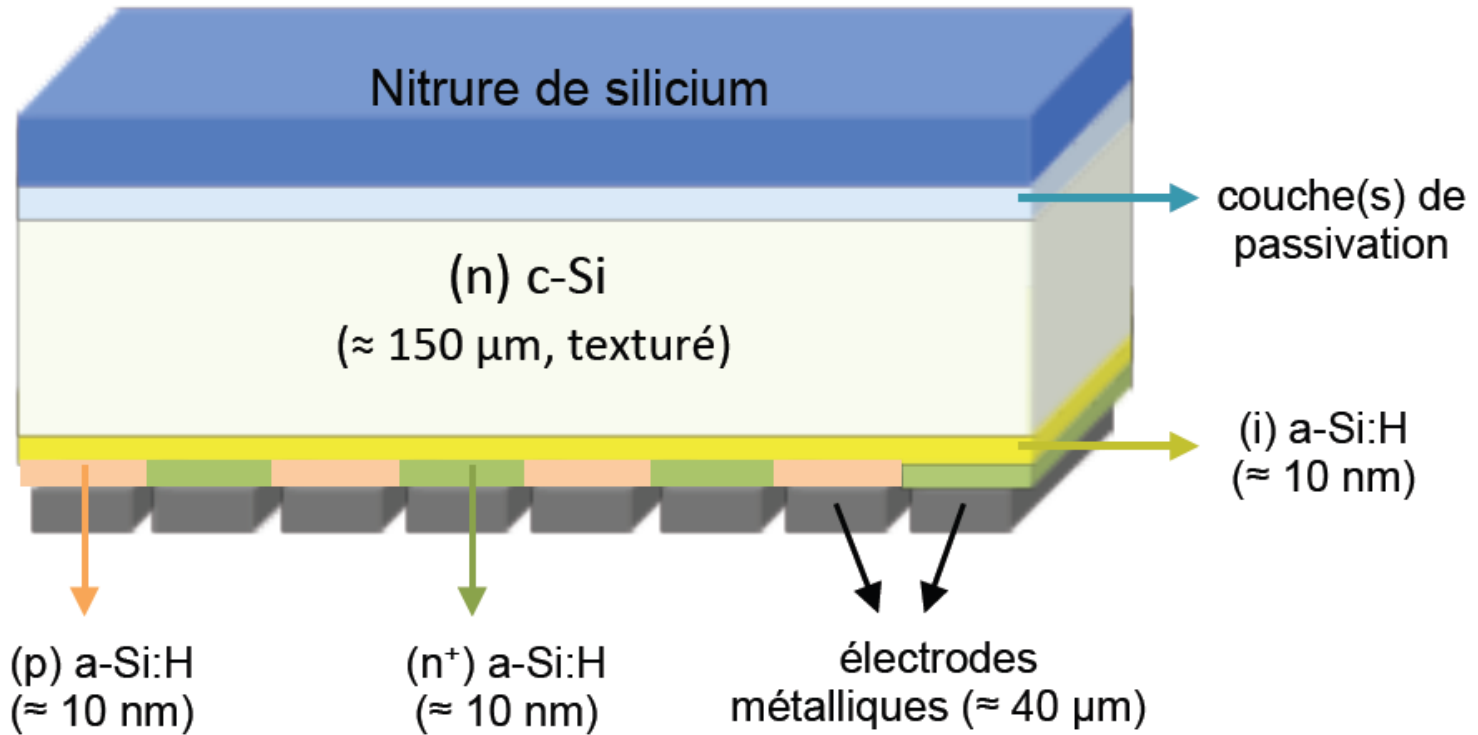
Keiichiro Masuko, Masato Shigematsu, Taiki Hashiguchi, Daisuke Fujishima, Motohide Kai, Naoki Yoshimura, Tsutomu Yamaguchi, Yoshinari Ichihashi, Takahiro Mishima, Naoteru Matsubara, Tsutomu Yamanishi, Tsuyoshi Takahama, Mikio Taguchi, Eiji Maruyama, and Shingo Okamoto

TABLE I
PROGRESS IN CELL PARAMETERS

Year	2013	2014	Improvement
Area [cm ²]	101.8	143.7	
Thickness [μ m]	98	150	
V_{oc} [V]	0.750	0.740	-1.3%
J_{sc} [mA/cm ²]	39.5	41.8	+5.8%
F.F. [%]	83.2	82.7	-0.6%
E_{ff} [%]	24.7	25.6	+3.6%



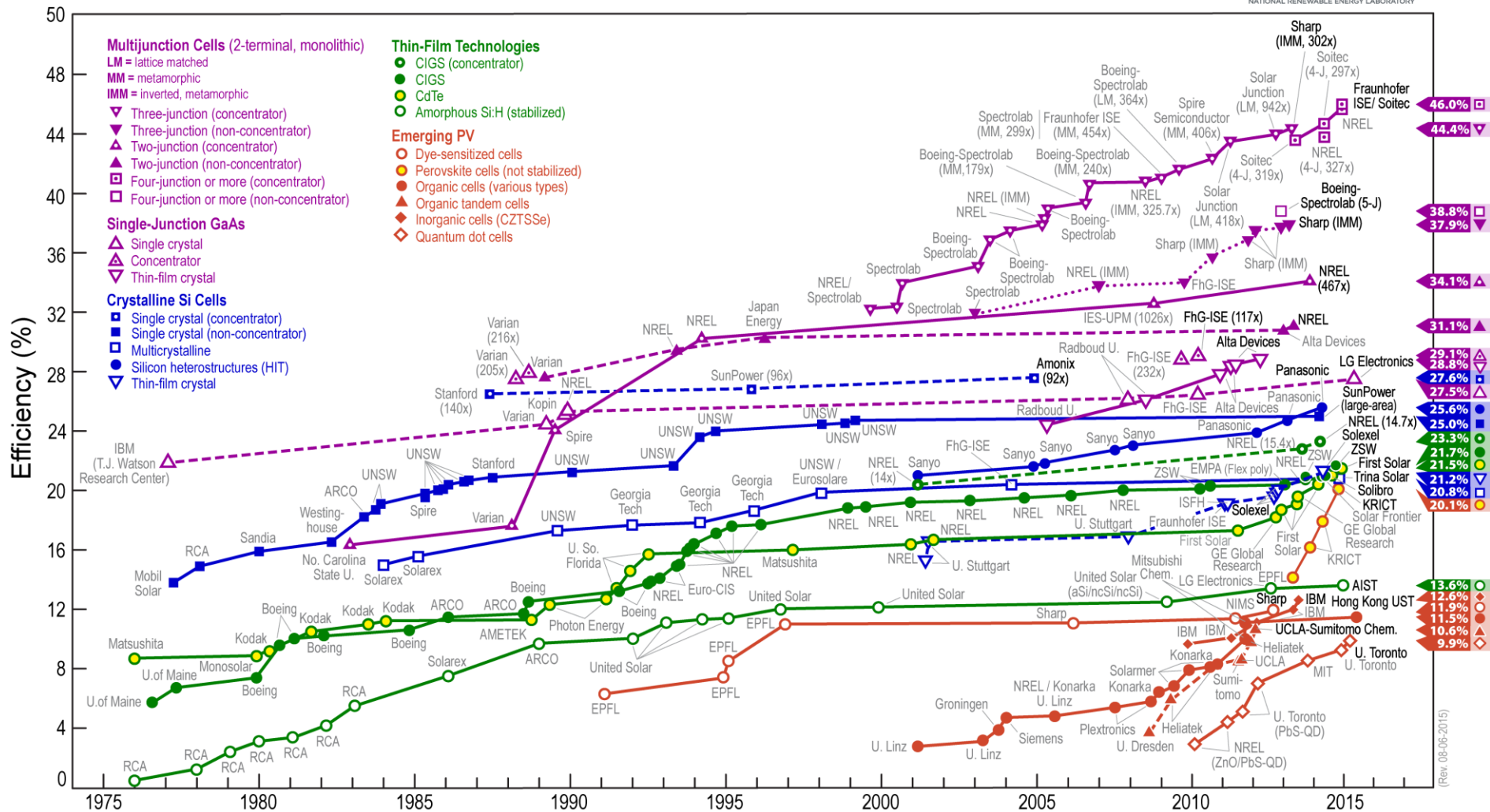
2014 : Structure de la cellule solaire record



Dessin: Jean Paul Kleider, CNRS

Les différentes technologies photovoltaïques

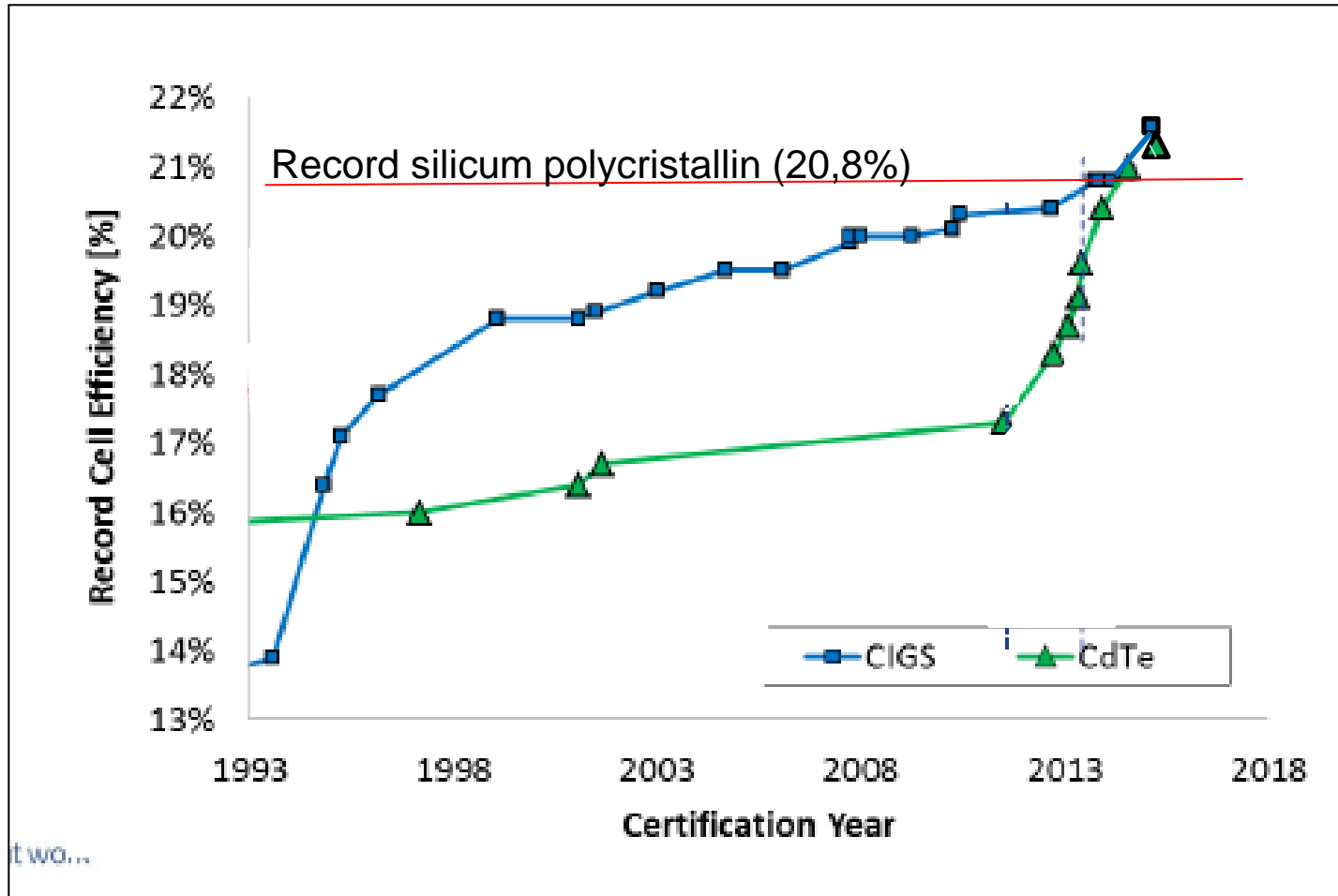
Best Research-Cell Efficiencies



(Rev. 08-06-2015)

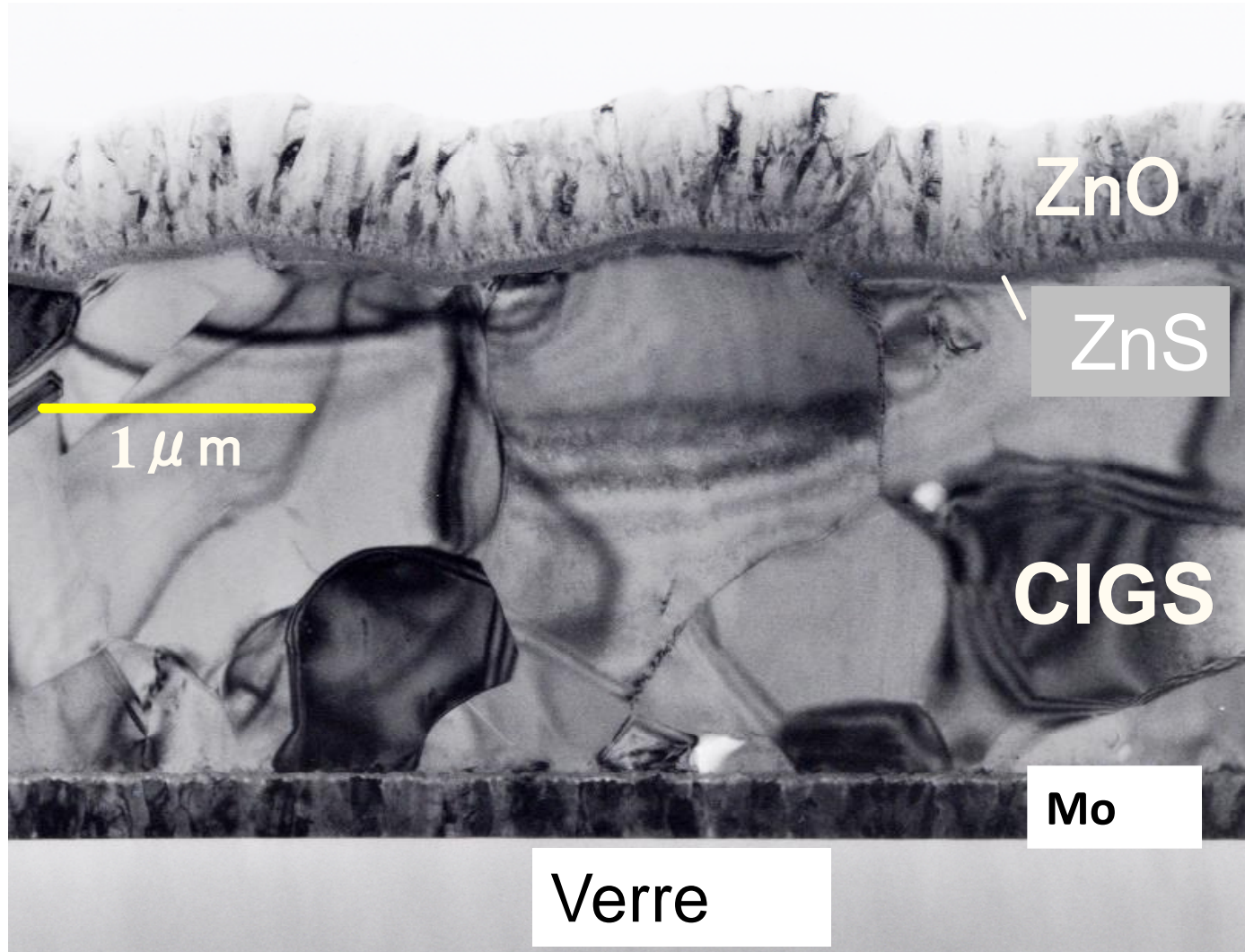
Les filières photovoltaïques en couches minces (quelques microns d'épaisseur)

- Silicium amorphe & microcristallin (rendement 13,5%) :
- CdTe : Tellure de cadmium (rendement 21,5%) noté CdTe
- Diséléniure de cuivre de gallium et d'indium (rendement 21,7%) noté CIGS



t wo...

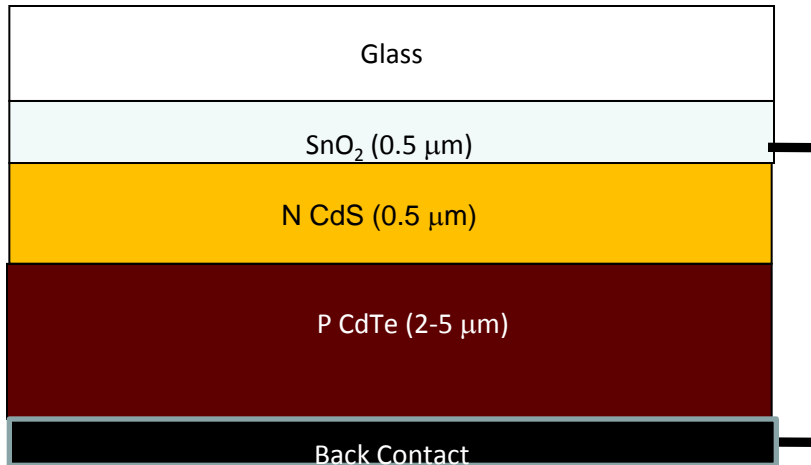
Coupe transverse d'une Cellule en couches minces au $\text{Cu}(\text{In,Ga})\text{Se}_2$ noté CIGS



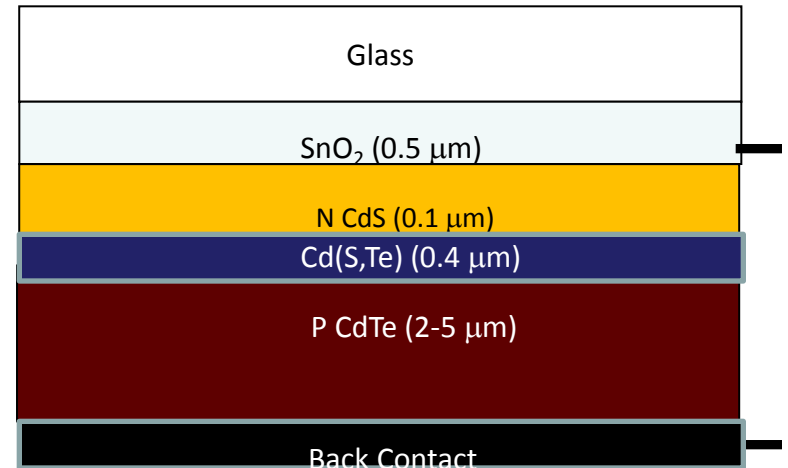
Cellules solaires au CdTe

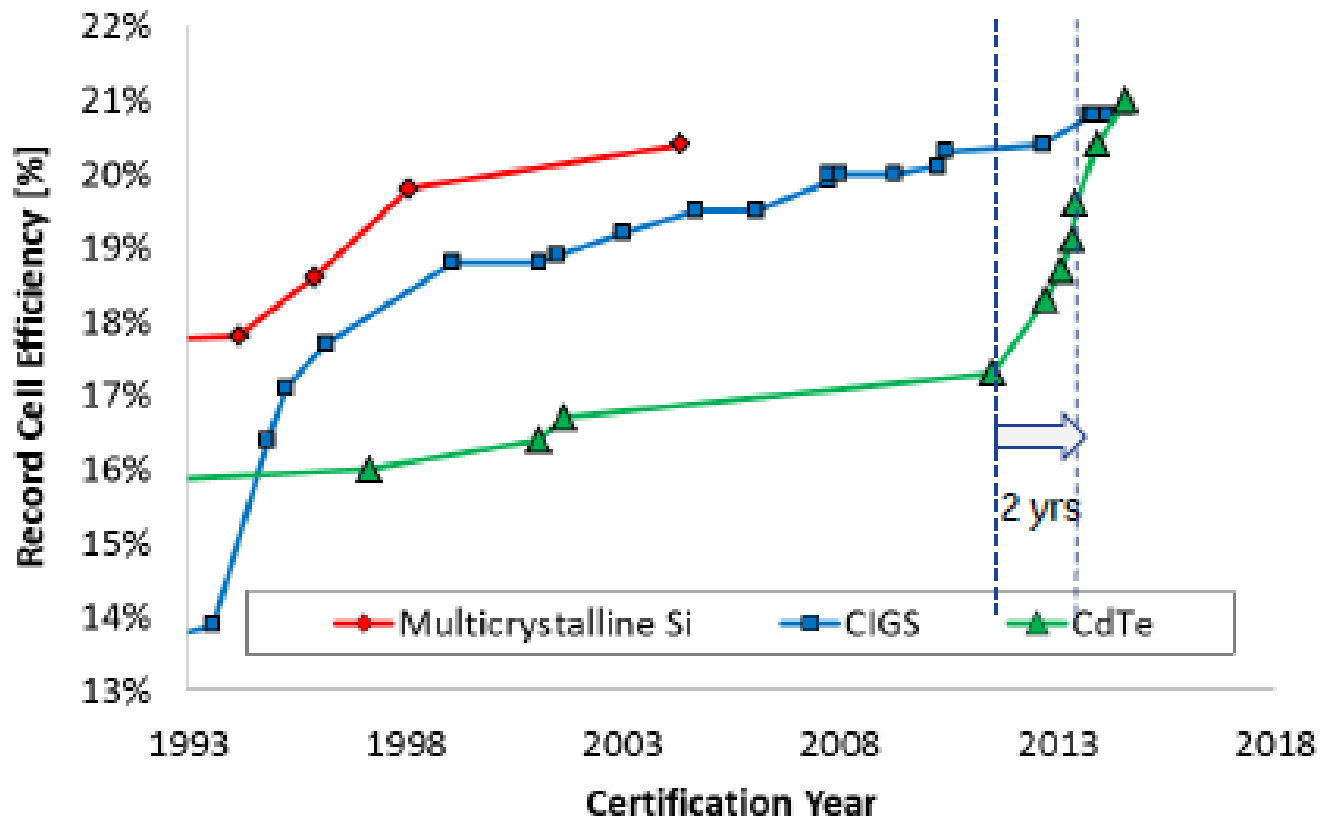
Les cellules solaires CdTe

Avant traitement thermique



Après traitement (400-500°C)

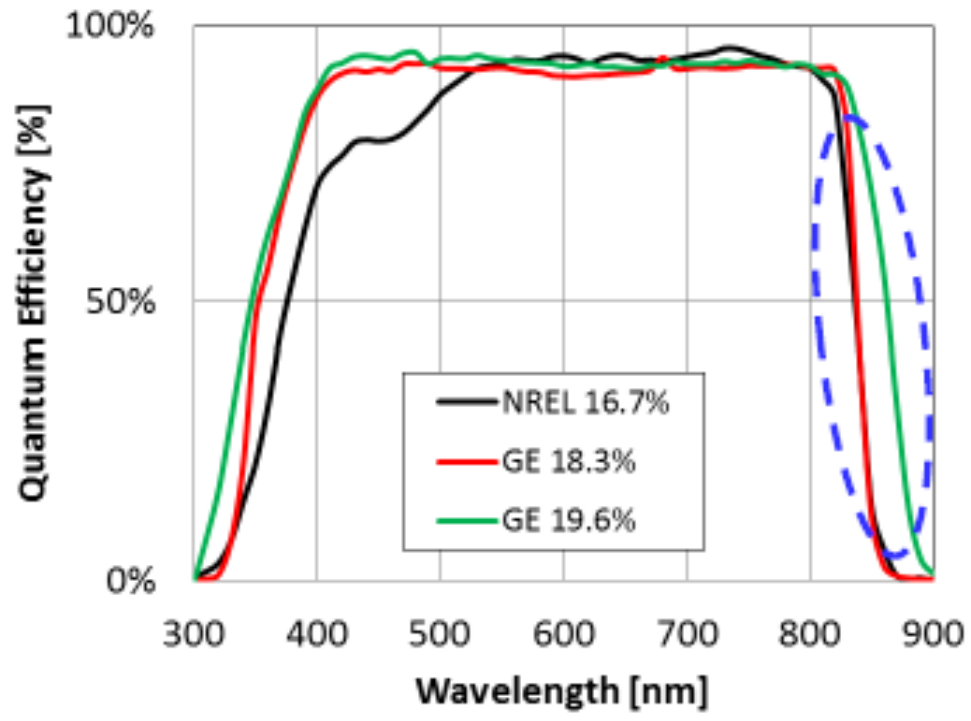




it wo...

Nouveaux TCO
CdSnO₃
CdZnO₃
Zn-In-O
Ga-Zn-O

(Cd,Zn)S
Gap augmente



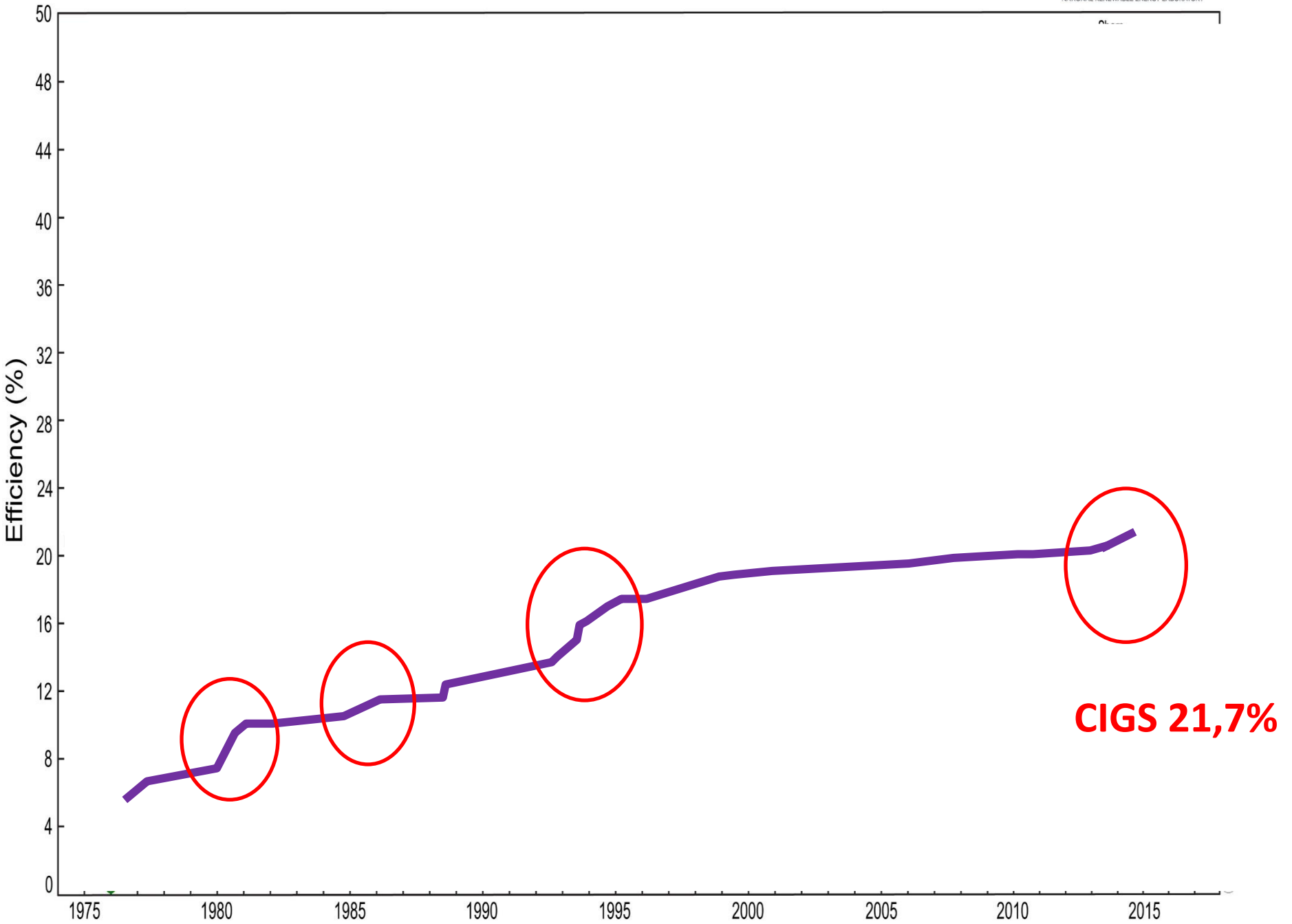
Cd(S,Te)
Gap diminue

(Cd,Zn)Te
(Cd,Mg)Te
Gap augmente

2015 : 21,5 %

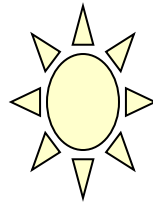
Cellules solaires au CIGS

Best Research-Cell Efficiencies

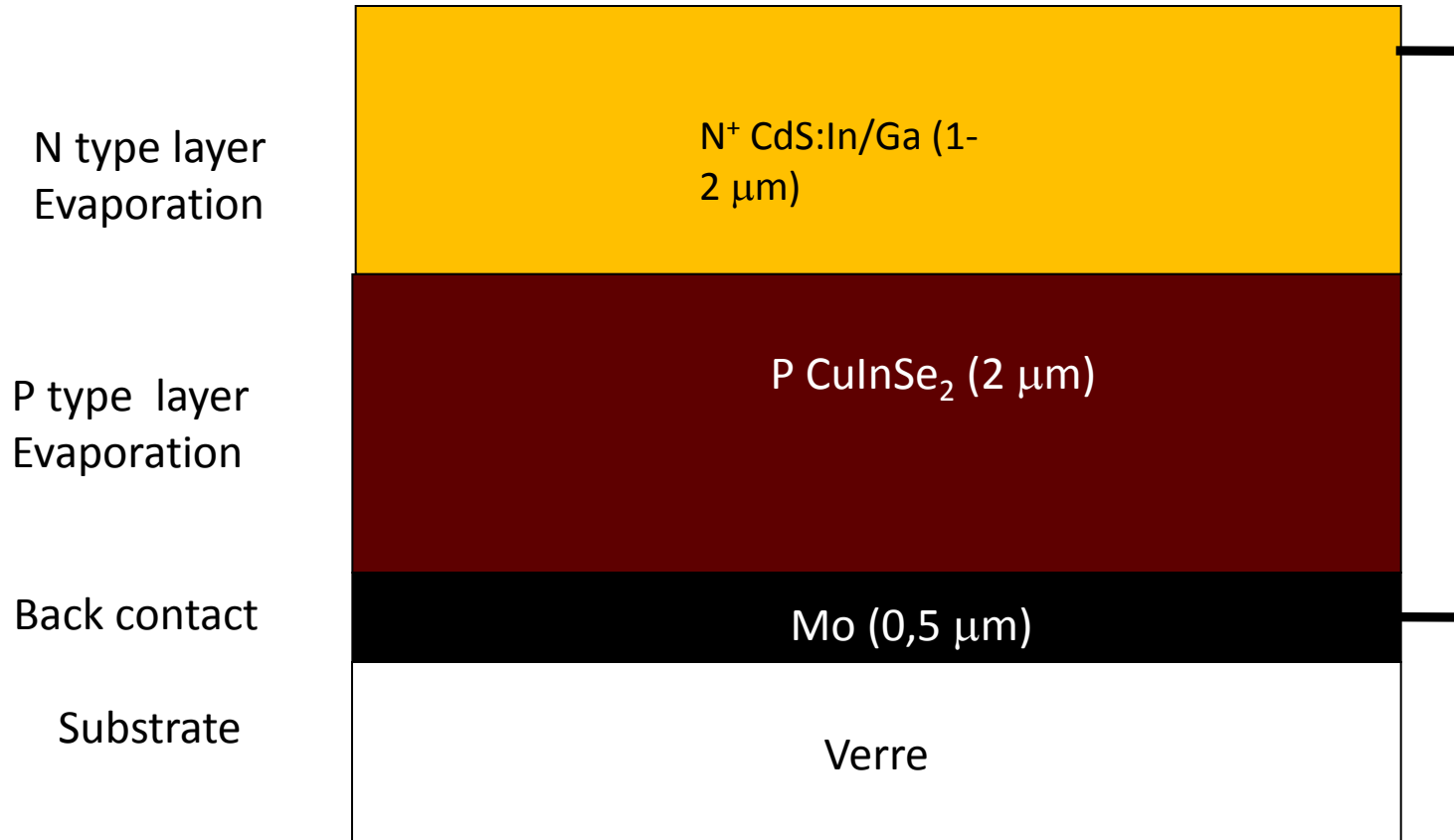


<1980

8%



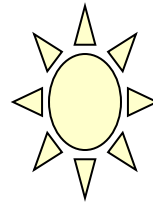
Contacts



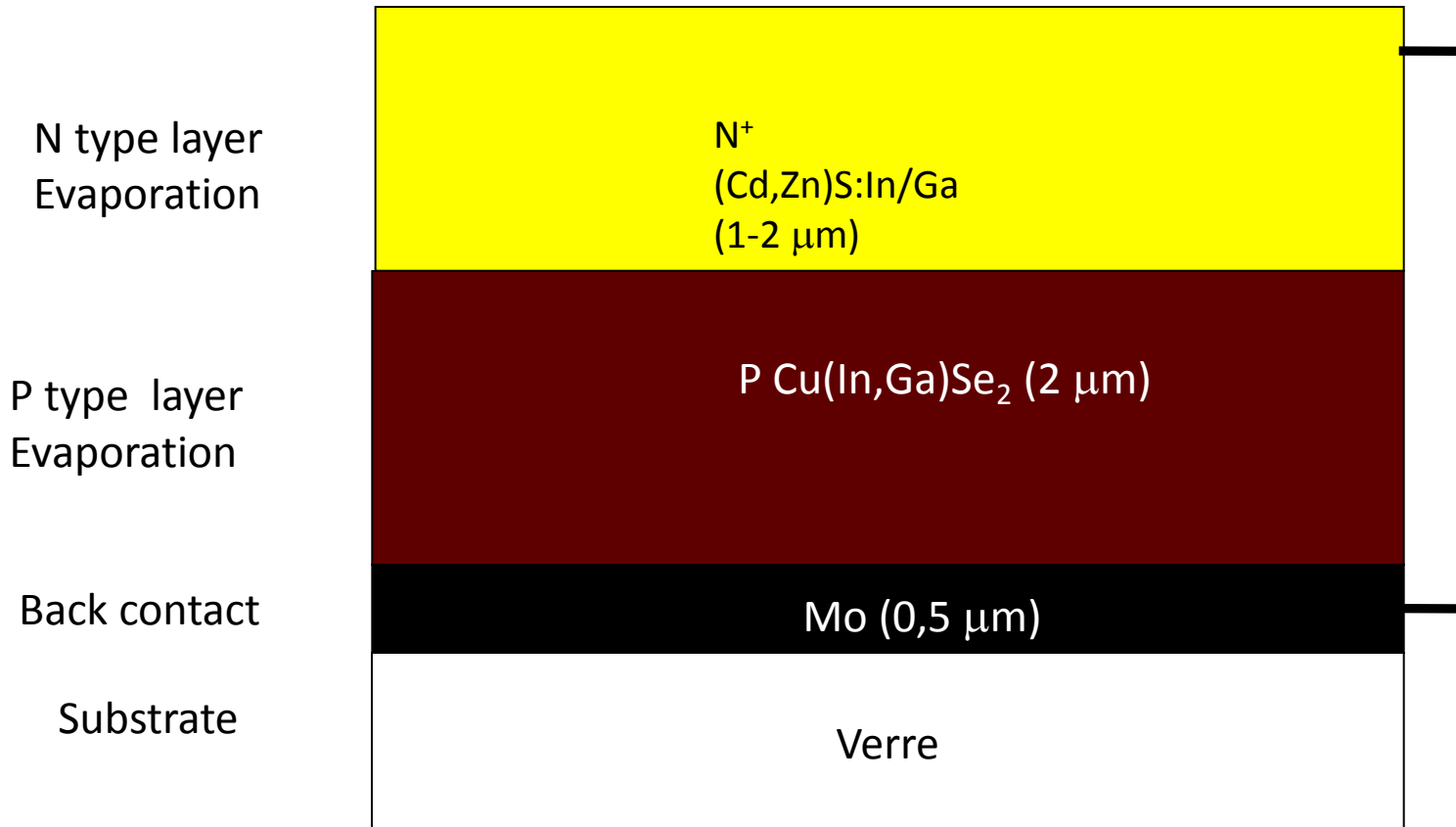
Not to scale

1985

12%



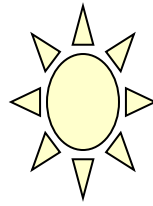
Contacts



Not to scale

1994

15%



Contacts

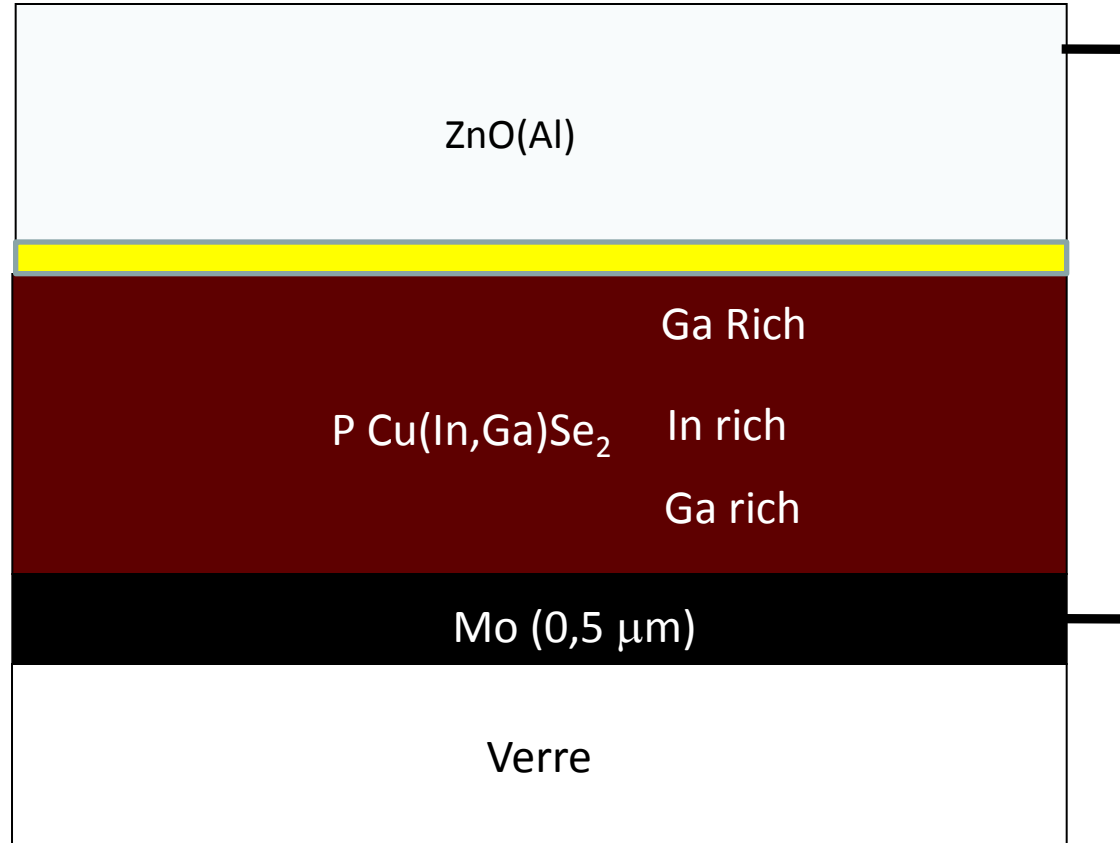
ZnO(Al)
By Sputtering

CdS by Solution (CBD)

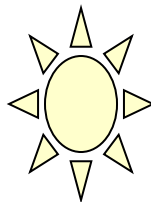
P type layer
By coEvaporation
3 stage process

Back contact

Substrate



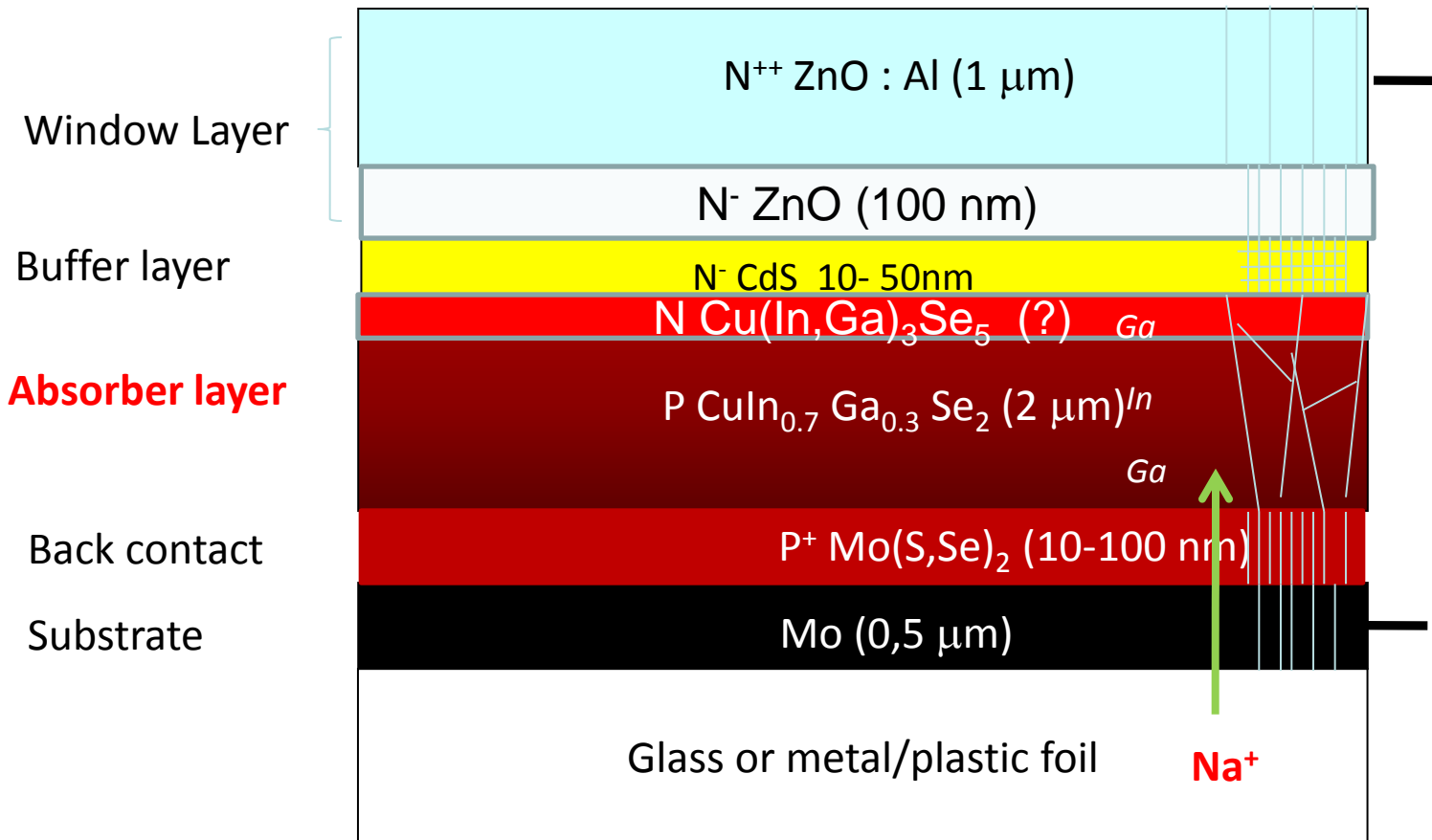
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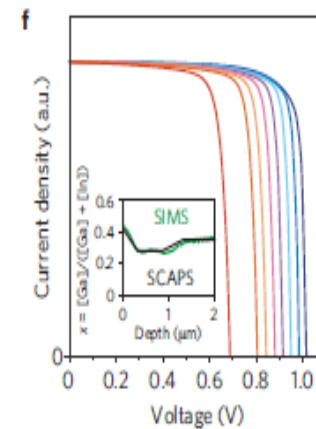
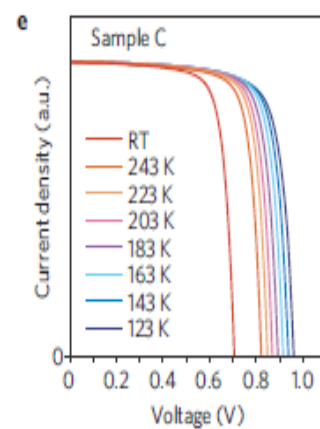
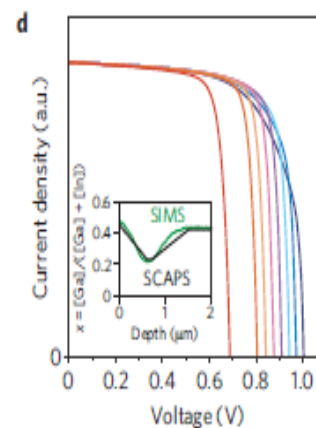
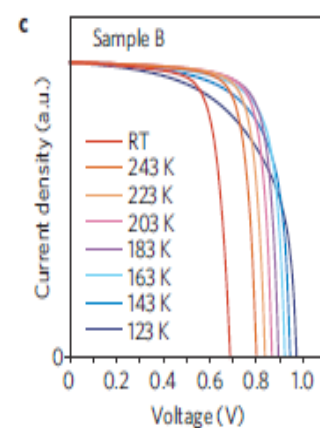
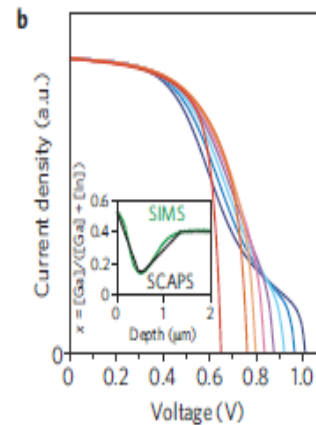
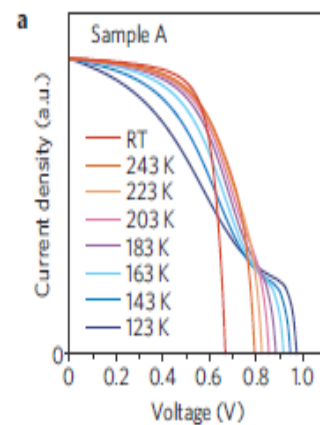
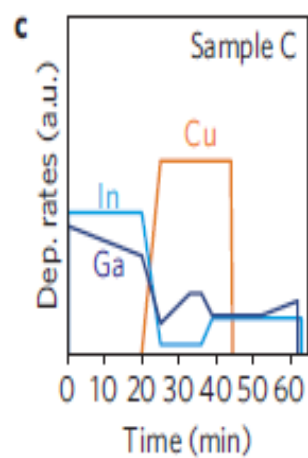
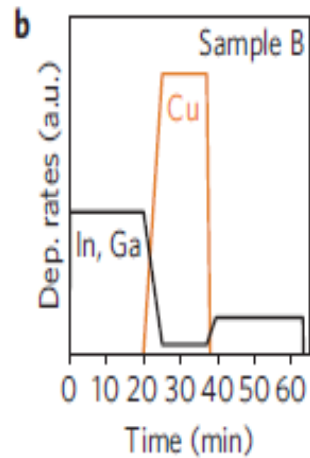
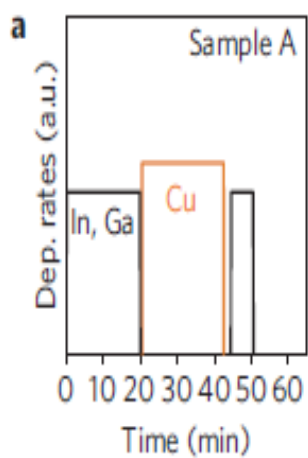
2010-2015

20%

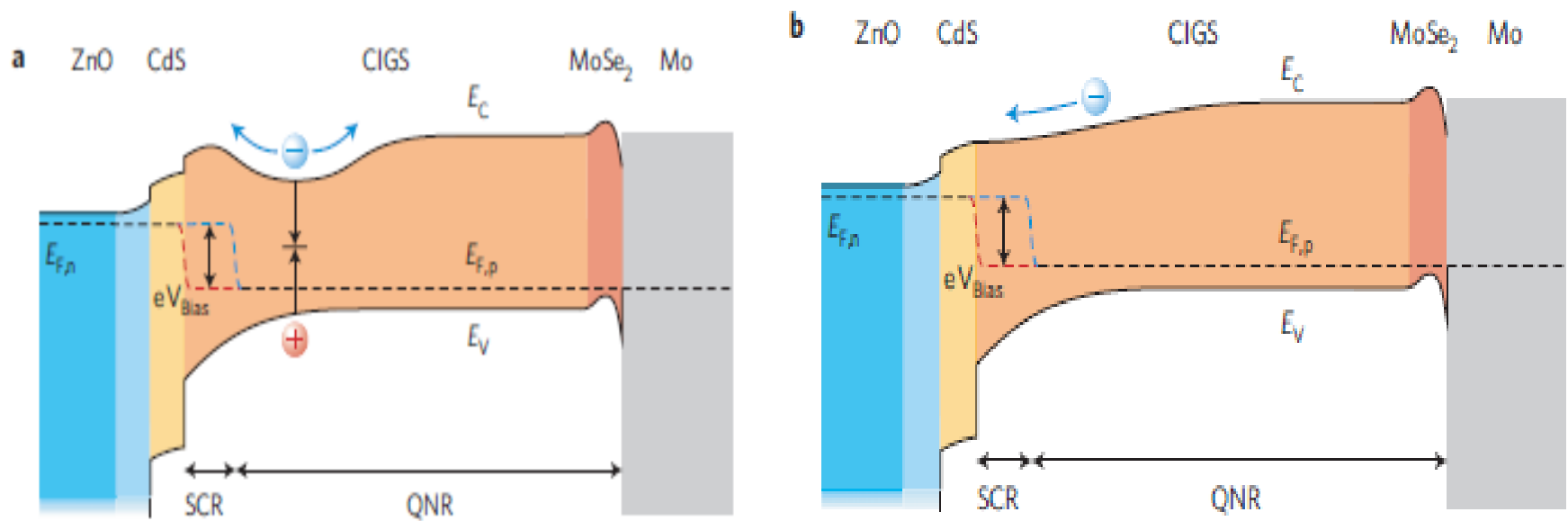
Contacts



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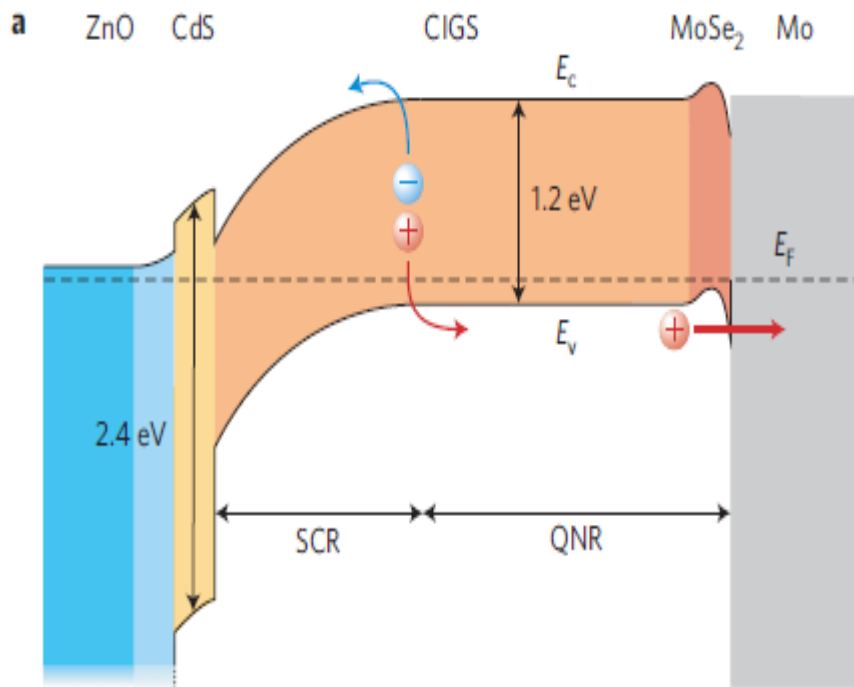


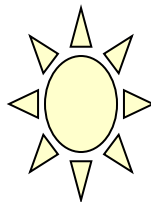
Record efficiency 20,4 % on plastics



Highly efficient $\text{Cu}(\text{In,Ga})\text{Se}_2$ solar cells grown on flexible polymer films

Adrian Chirilă^{1*}, Stephan Buecheler¹, Fabian Pianezzi¹, Patrick Bloesch¹, Christina Gretener¹, Alexander R. Uhl¹, Carolin Fella¹, Lukas Kranz¹, Julian Perrenoud¹, Sieghard Seyrling¹, Rajneesh Verma¹, Shiro Nishiwaki¹, Yaroslav E. Romanyuk¹, Gerhard Bilger² and Ayodhya N. Tiwari¹

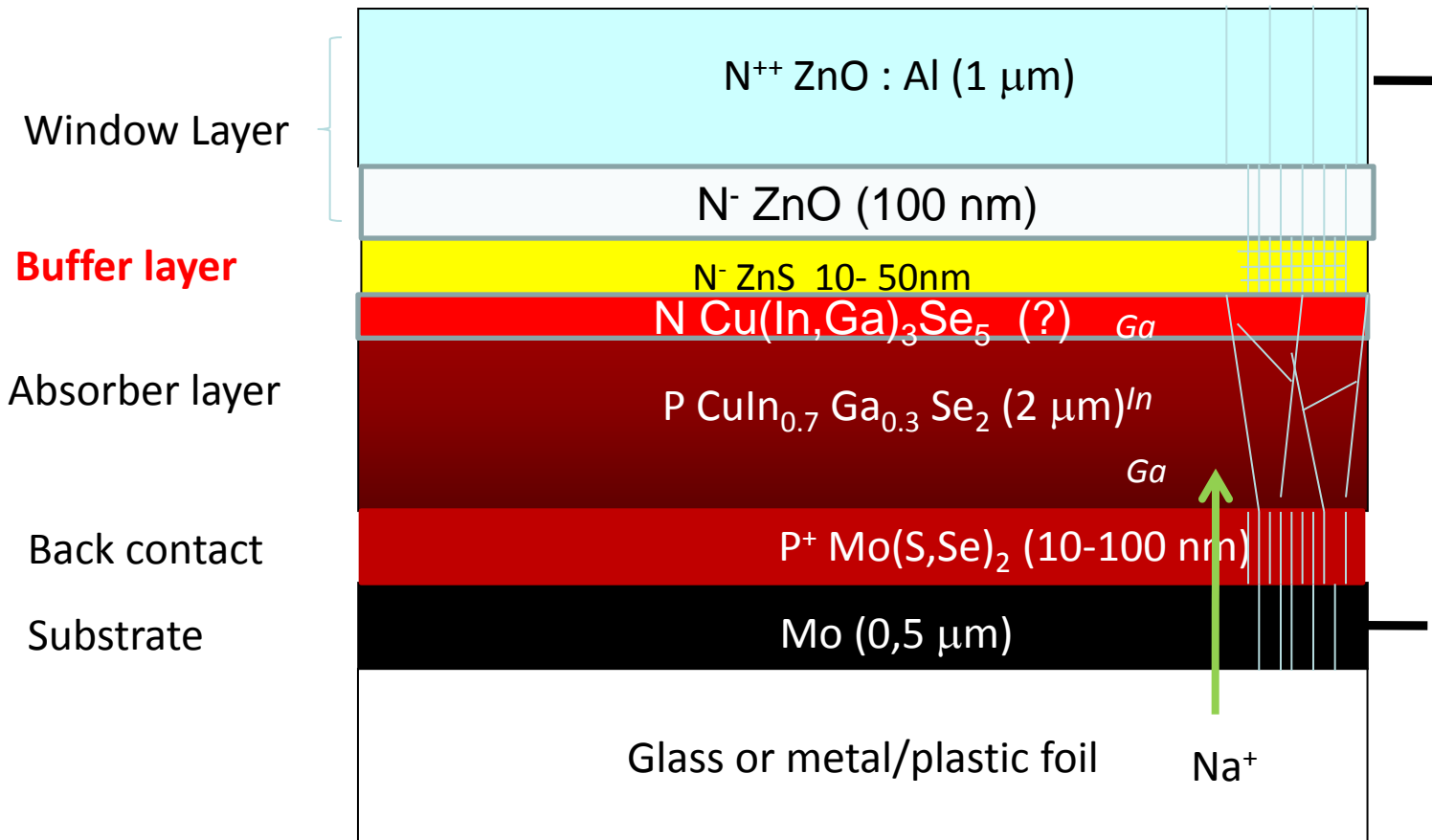




2015

21%

Contacts



Not to scale

SPECIAL ISSUE PAPER

Buffer layers and transparent conducting oxides for chalcopyrite $\text{Cu}(\text{In,Ga})(\text{S,Se})_2$ based thin film photovoltaics: present status and current developments

N. Naghavi^{1*}, D. Abou-Ras², N. Allsop², N. Barreau³, S. Bücheler⁴, A. Ennaoui², C.-H. Fischer², C. Guillen⁵, D. Hariskos⁶, J. Herrero⁵, R. Klenk², K. Kushiya⁷, D. Lincot¹, R. Menner⁶, T. Nakada⁸, C. Platzer-Björkman⁹, S. Spiering⁶, A.N. Tiwari⁴ and T. Törndahl⁹

Route for Cd free devices and Higher efficiency devices (25%) with increased Short Circuit Currents

Approaches for ZnS based window layers

n-type windows	r.f. ZnO:Al	MOCVD ZnO:B	r.f. ZnO:Al	r.f. ZnO:Al	r.f. ZnO:Al	r.f. ZnO:Al
			r.f. i-ZnO	r.f. i-ZnO	r.f. Zn _{1-x} Mg _x O	r.f. Zn _{1-x} Mg _x O
Buffer	Zn(S,O,H)	Zn(S,O,H)	Zn(S,O)	Zn(S,O)	Zn(S,O,H)	Zn(S,O,H)
p-type absorber	Cu(In,Ga)Se ₂	Cu(In,Ga)(S,Se) ₂ Cu(In,Ga)Se ₂	CuInS ₂	Cu(In,Ga)(S,Se) ₂	Cu(In,Ga)Se ₂	ED-CuIn(S,Se) ₂
Metal Based Electrode	Mo	Mo	Mo	Mo	Mo	Mo
substrate	Soda-lime Glass	Soda-lime Glass	Soda-lime Glass	Soda-lime Glass	Soda-lime Glass	Soda-lime Glass

Nakada & al.
Contreras & al.

Kushiya & al.

Ennaoui & al.

Hariskos & al.

Hubert & al.

Evolution de l'interface Mo/Cu(GaIn)Se₂ dans les cellules photovoltaïques en couche mince à base de CIGS en fonction du temps de sélénisation du Mo.

B. Theys*, G. Patriarche**, T. Klinkert*, M. Jubault*, D. Lincot*

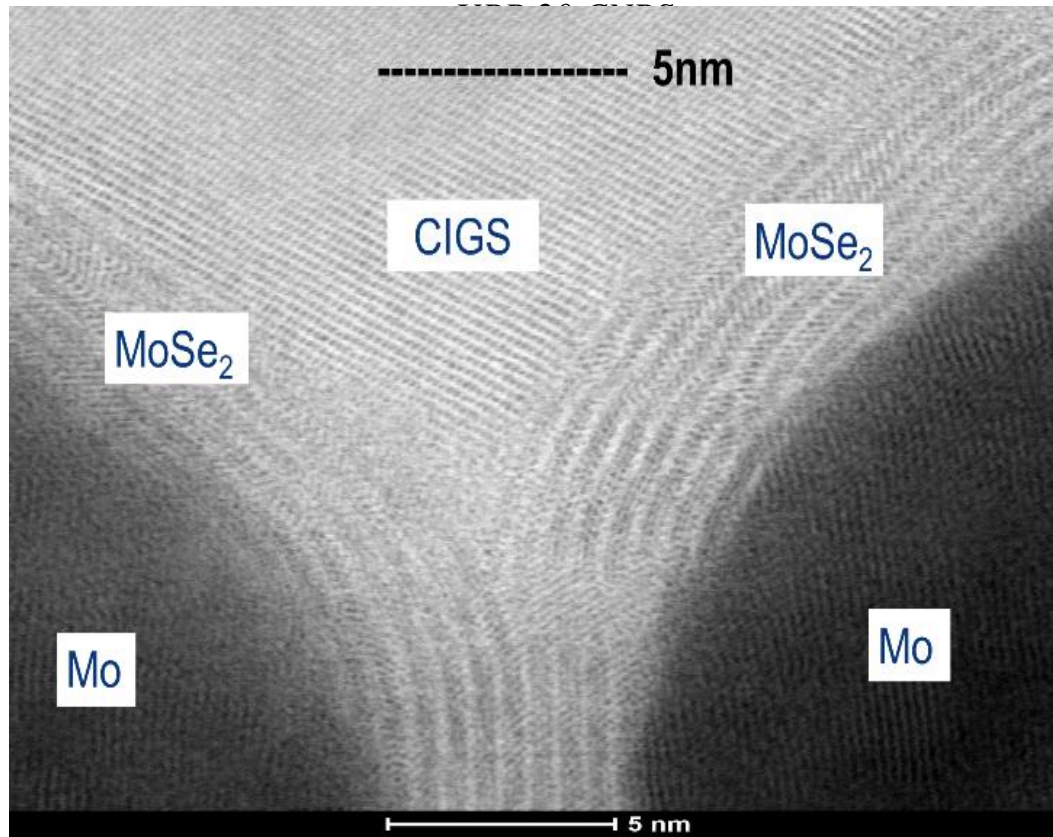
**Institut de Recherche et Développement de l'Energie photovoltaïque (IRDEP)*

UMR 7174 CNRS-Chimie ParisTech, EDF

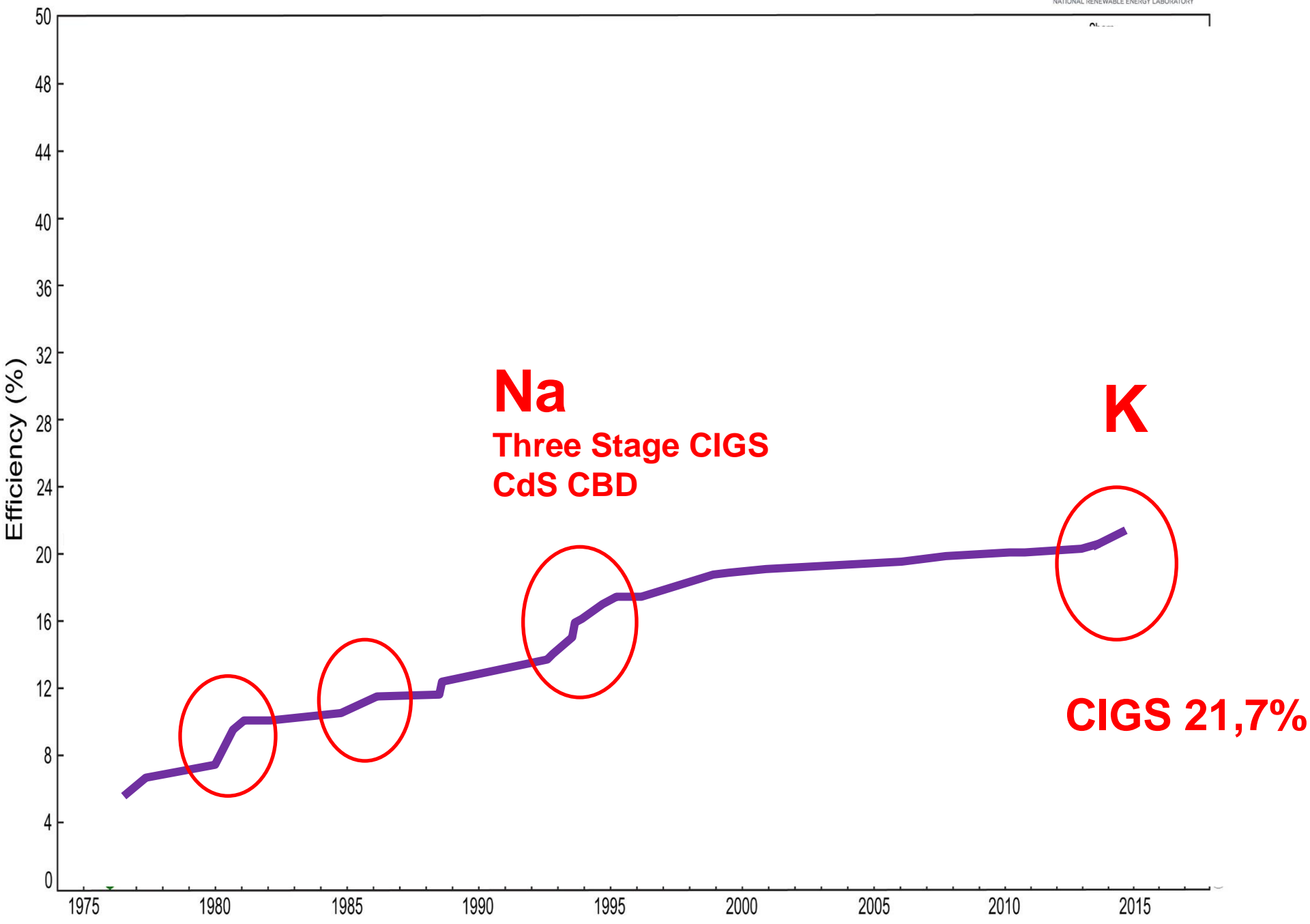
6, quai Watier 78400 Chatou

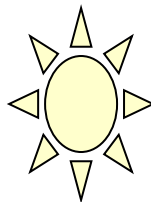
*** Laboratoire de Photonique et Nanostructures (LPN)*

Submitted 2015



Best Research-Cell Efficiencies

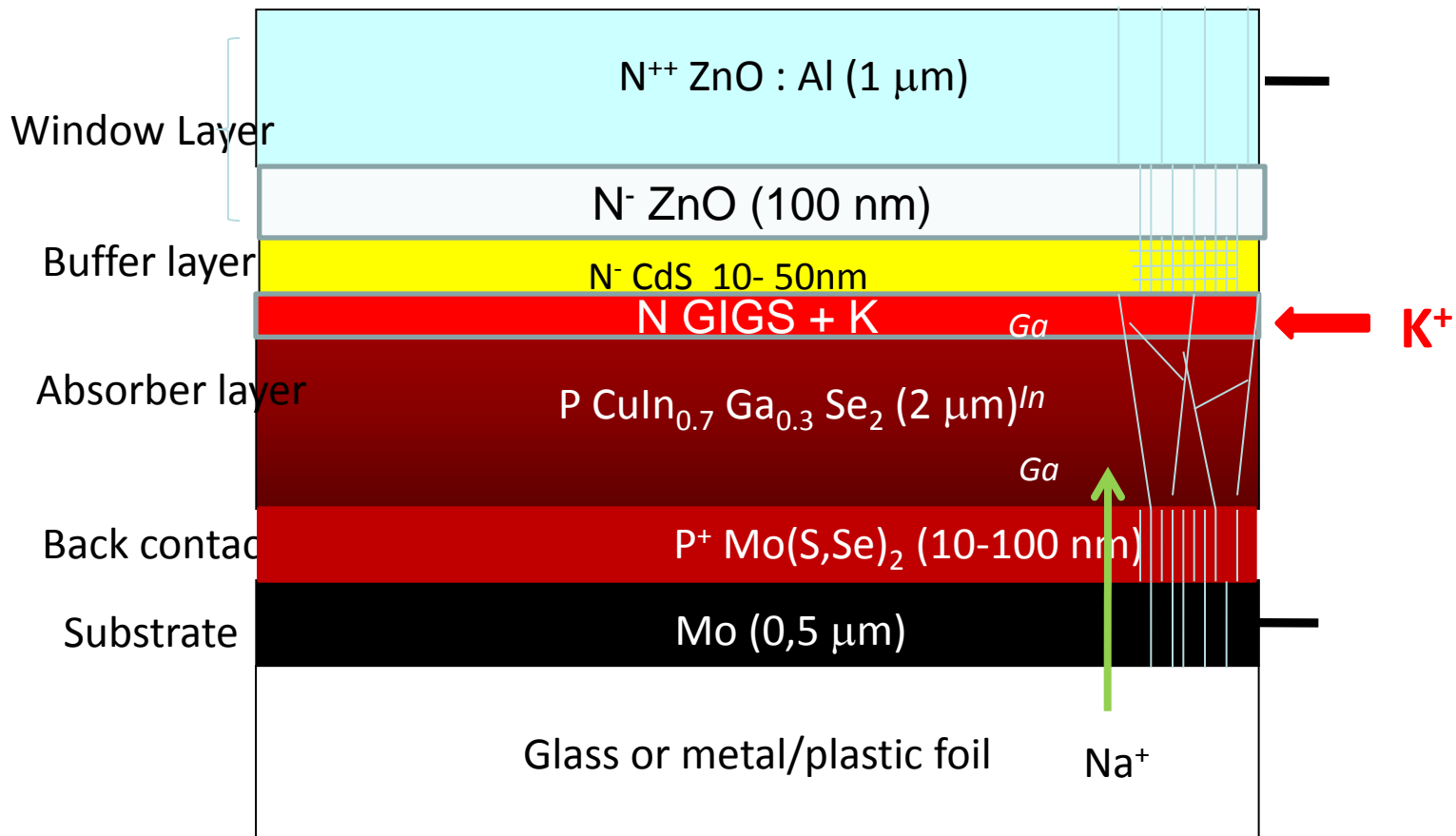




2014

21,7%

Contacts

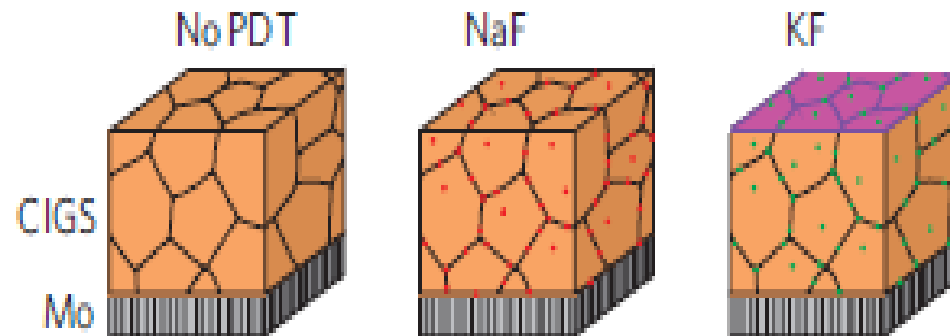


Not to scale

Potassium-induced surface modification of $\text{Cu}(\text{In,Ga})\text{Se}_2$ thin films for high-efficiency solar cells

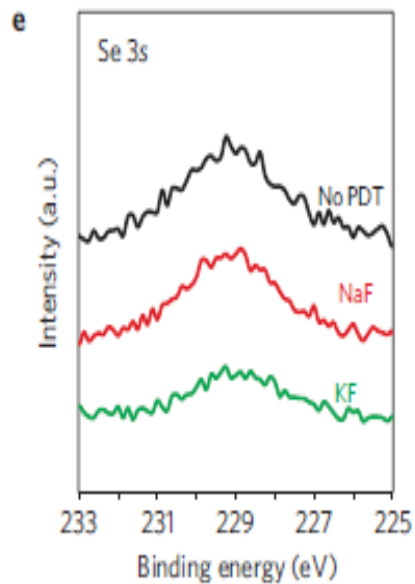
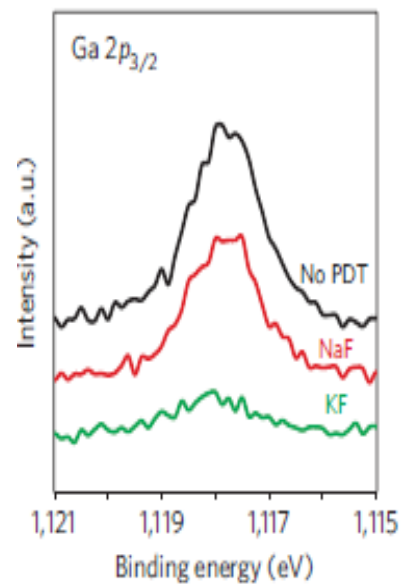
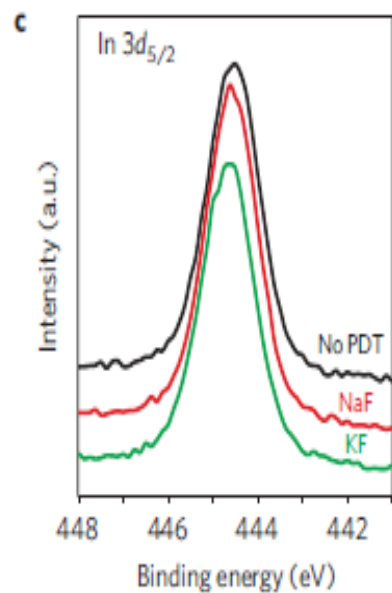
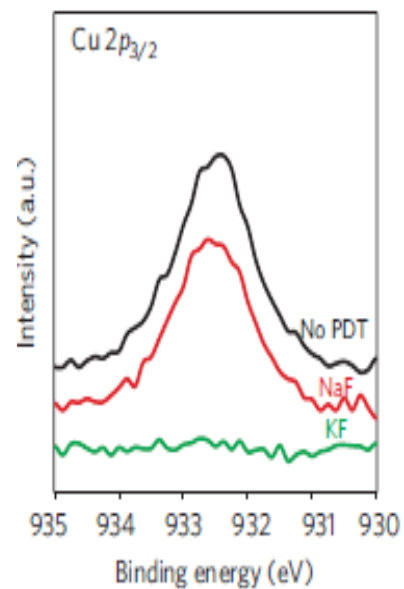
Adrian Chirilă^{1*†}, Patrick Reinhard^{1†}, Fabian Pianezzi¹, Patrick Bloesch¹, Alexander R. Uhl¹, Carolin Fella¹, Lukas Kranz¹, Debora Keller¹, Christina Gretener¹, Harald Hagendorfer¹, Dominik Jaeger², Rolf Erni³, Shiro Nishiwaki¹, Stephan Buecheler¹ and Ayodhya N. Tiwari¹

20.4 %
Word
Record
On plastic
350°C



Post deposition treatments (GB and Surface)

Received 14 May 2013; accepted 25 September 2013;
published online 3 November 2013



Influence of grain boundary modification on limited performance of wide bandgap Cu(In,Ga)Se₂ solar cells

M. Raghuwanshi,^{1,a)} E. Cadel,¹ P. Pareige,¹ S. Duguay,¹ F. Couzinie-Devy,² L. Arzel,² and N. Barreau²

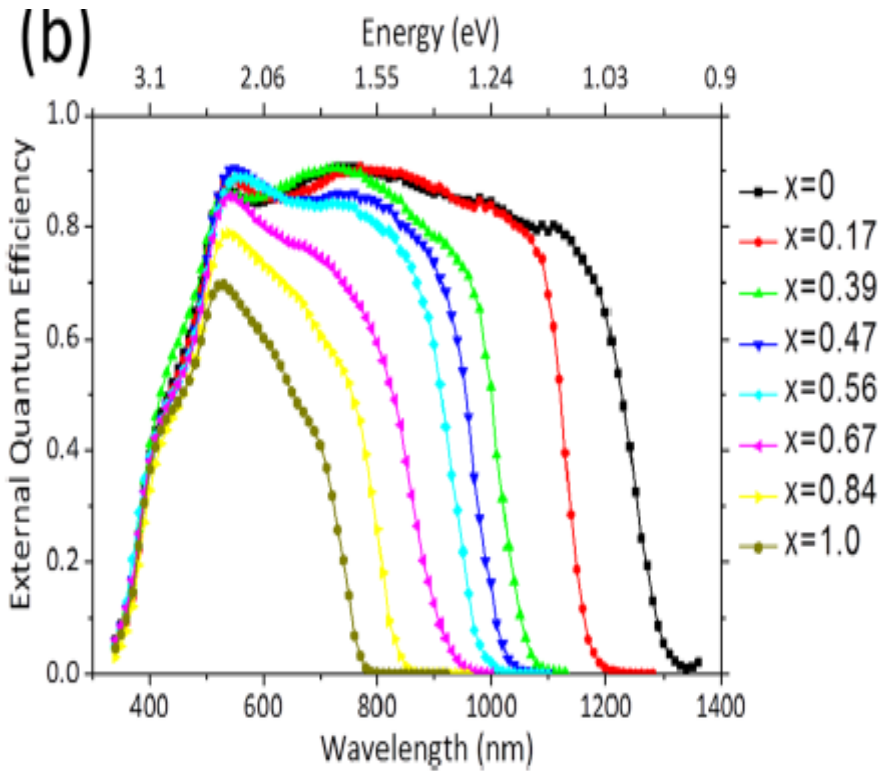
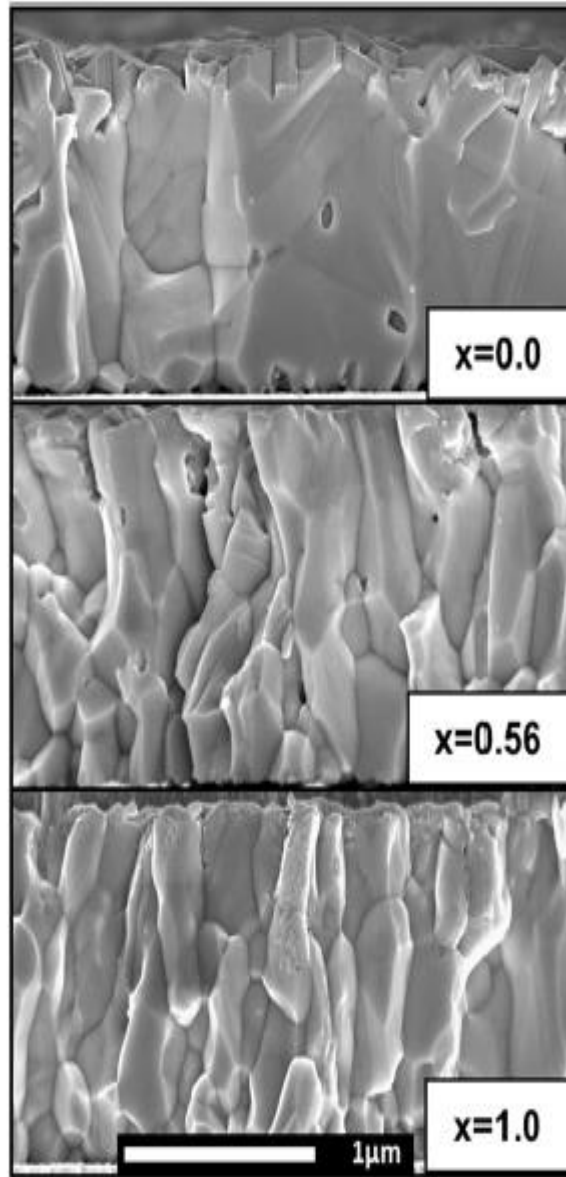
¹*Groupe de Physique des Matériaux (GPM), UMR 6634 CNRS, Université et INSA de Rouen, Avenue de l'Université BP 12, 76801 Saint Etienne du Rouvray, France*

²*Institut des Matériaux Jean Rouxel (IMN), UMR 6502 CNRS, Université de Nantes, 2 rue de la Houssinière BP 32229, 44322 Nantes cedex 3, France*

(Received 17 June 2014; accepted 1 July 2014; published online 10 July 2014)

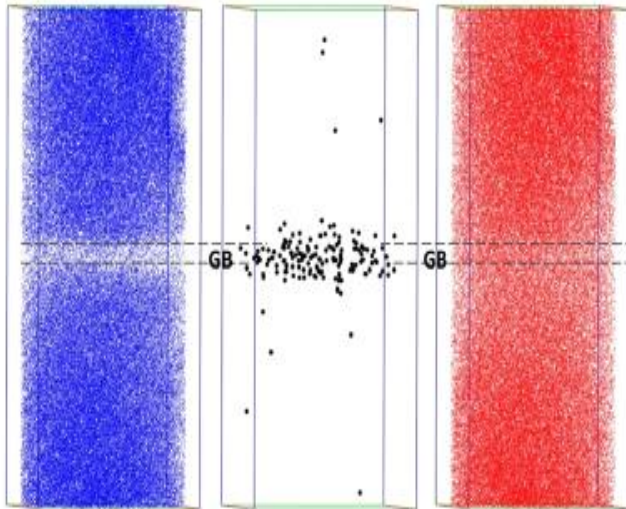
Cell performances

(a)



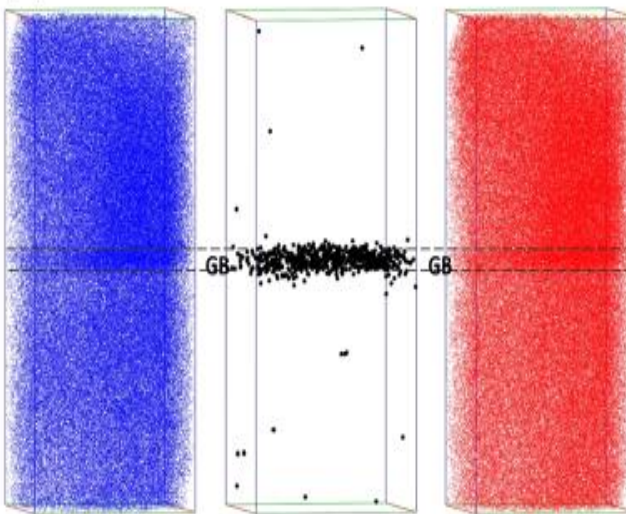
$$\Gamma_{Cu} = \frac{[Cu]^{GB} - [Cu]^{GI}}{[Cu]^{GI}}$$

(a) High Ga content



20 x 20 x 45 nm³

(b) Low Ga content

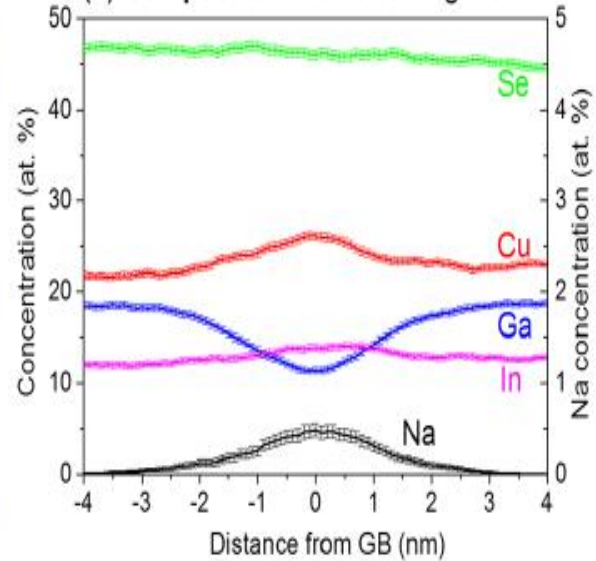


Ga

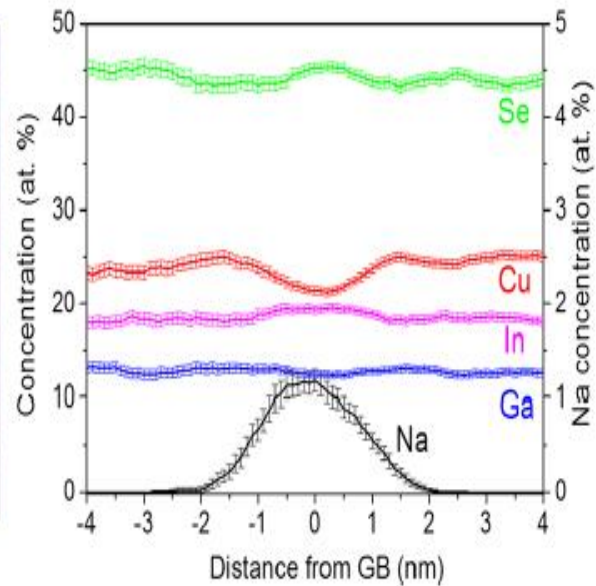
Na

Cu

(c) Composition Profile for High Ga



(d) Composition Profile for Low Ga

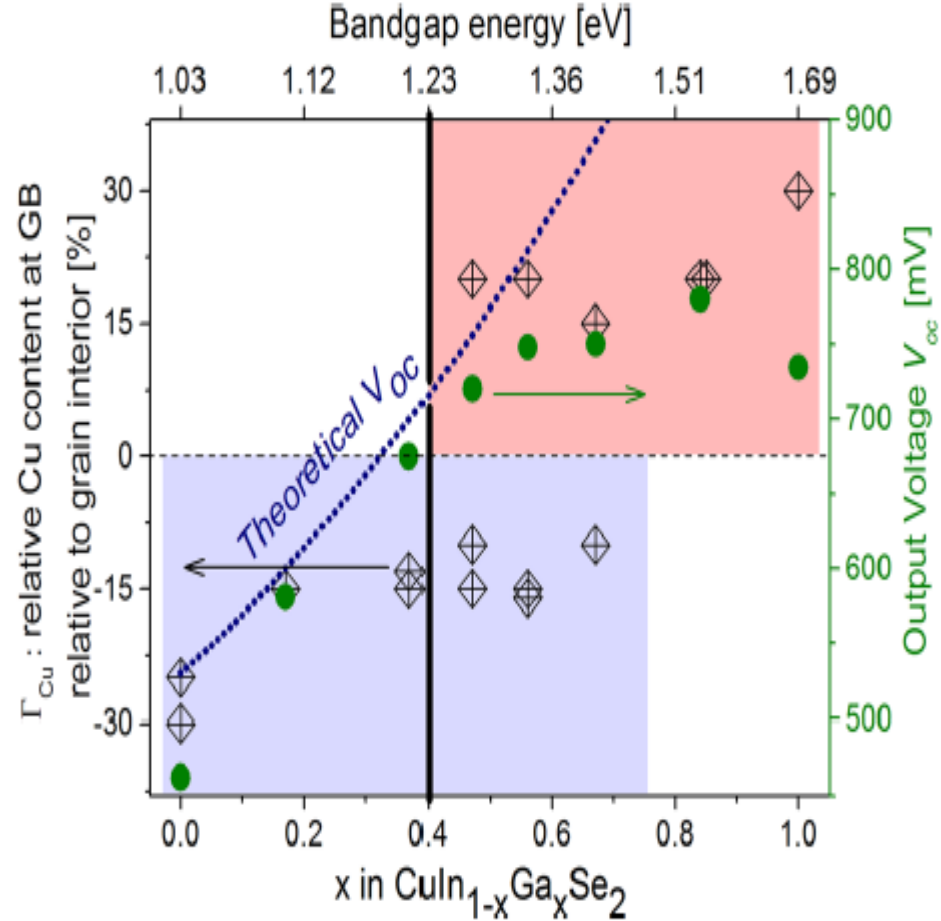
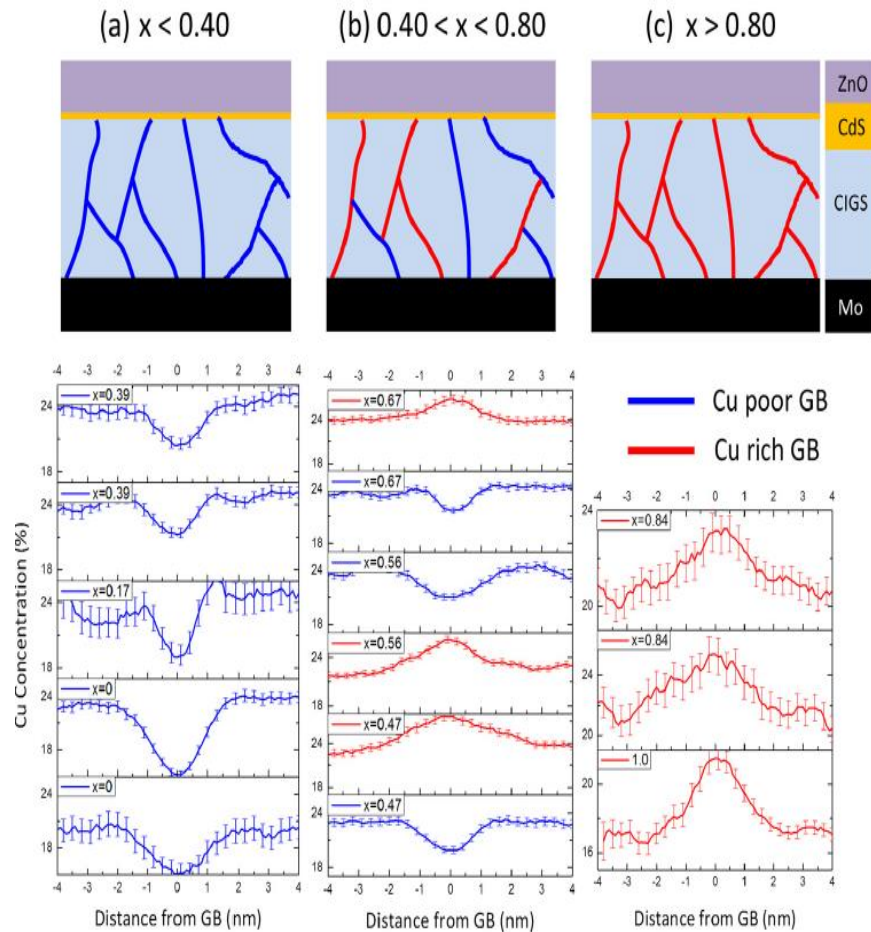


Cu Enriched GB

Na Poor GB

Cu depleted GB

Na Enriched GB



Cu depleted GB acts as a Hole barrier

Theoretical calculations

¹²C. Persson and A. Zunger, *Phys. Rev. Lett.* **91**, 266401 (2003).

Physics of grain boundaries in polycrystalline photovoltaic semiconductors

Yanfa Yan,^{1,a)} Wan-Jian Yin,¹ Yelong Wu,¹ Tingting Shi,¹ Naba R. Paudel,¹ Chen Li,² Jonathan Poplawsky,³ Zhiwei Wang,^{1,4} John Moseley,⁴ Harvey Guthrey,⁴ Helio Moutinho,⁴ Stephen J. Pennycook,⁵ and Mowafak M. Al-Jassim⁴

¹*Department of Physics and Astronomy and Wright Center for Photovoltaics Innovation and Commercialization, The University of Toledo, Ohio 43606, USA*

²*Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

³*The Center for Nanophase Materials Sciences, Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*

⁴*National Renewable Energy Laboratory, Golden, Colorado 80401, USA*

⁵*Department of Materials Science and Engineering, University of Tennessee, Knoxville, Tennessee 37996, USA*

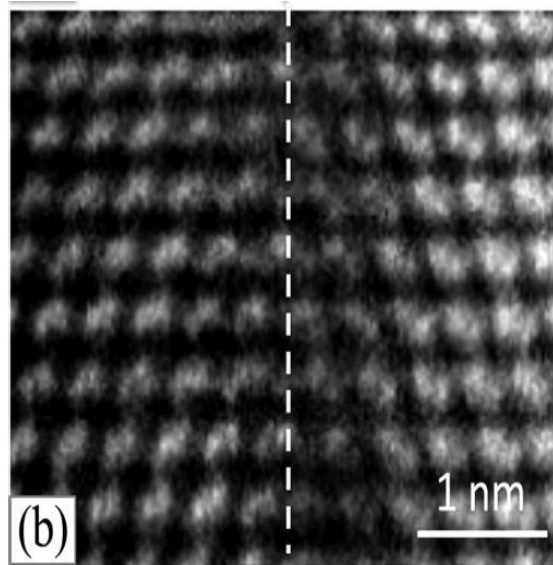
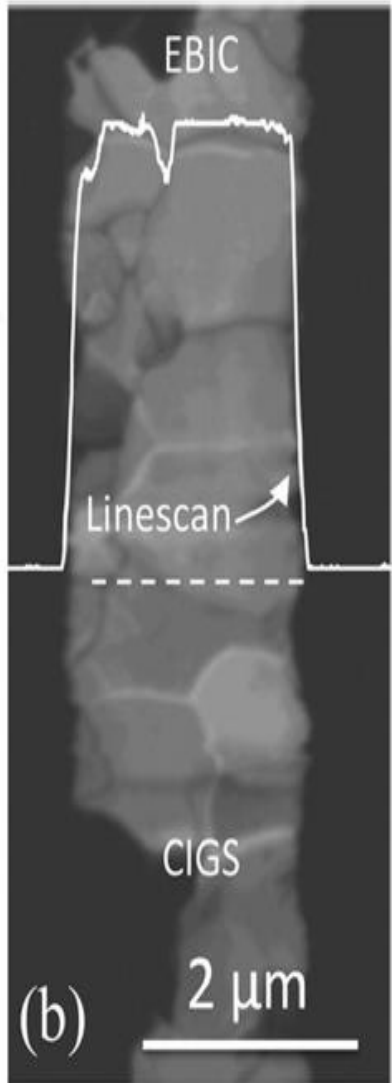


FIG. 2. Atomic-resolution aberration-corrected Z-contrast images of incoherent $\Sigma 3$ GBs in (a) CdTe and (b) CIGS.

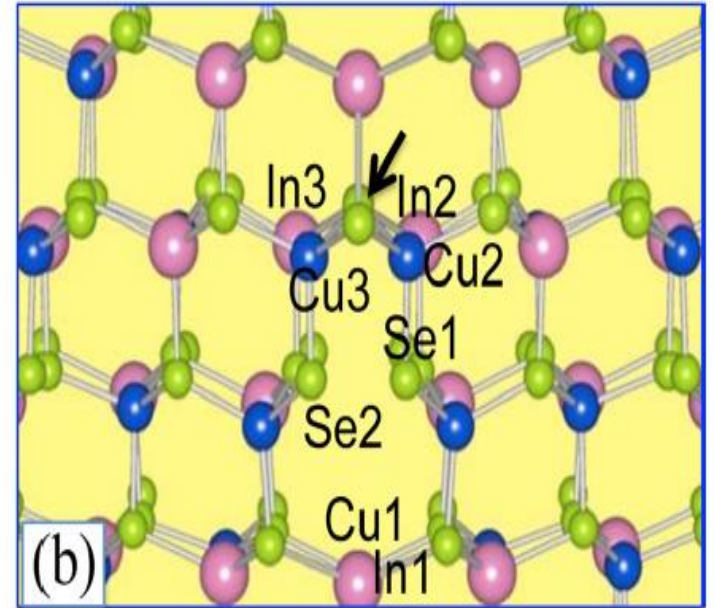


FIG. 3. Atomic structures of $\Sigma 3$ GBs in (a) CdTe and (b) CIGS.

State of Cu at GB still under question

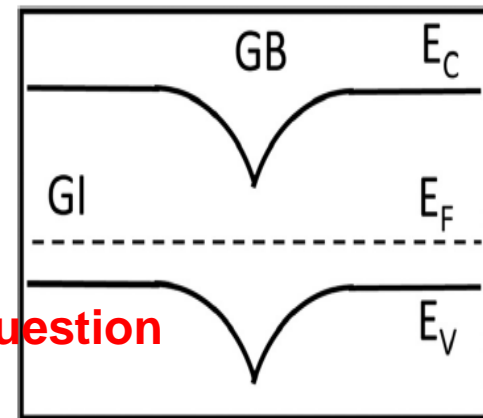
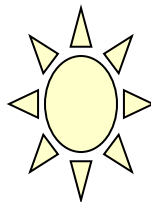
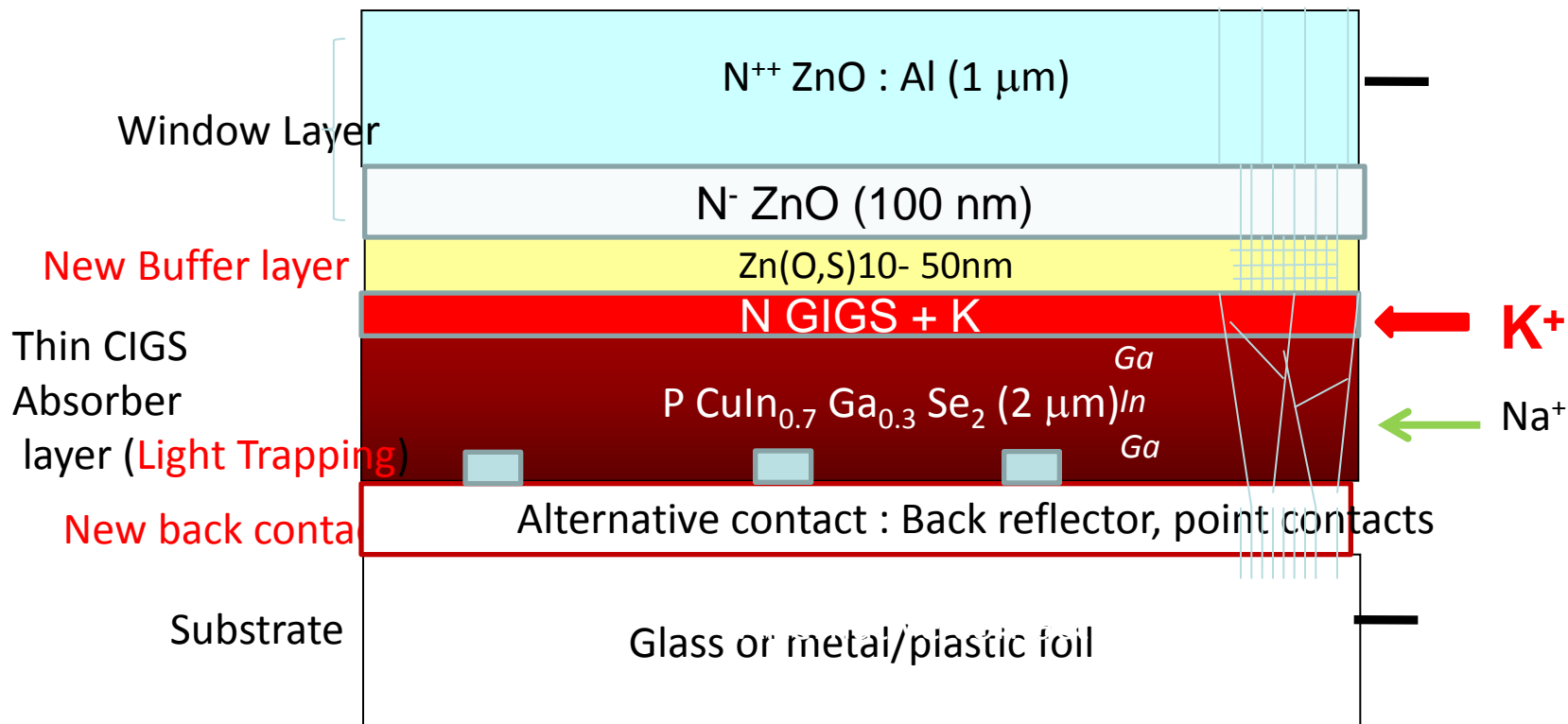


FIG. 7. A sketch showing the band diagram of the p-n-p junction at the GB.



> 2015
22-25%

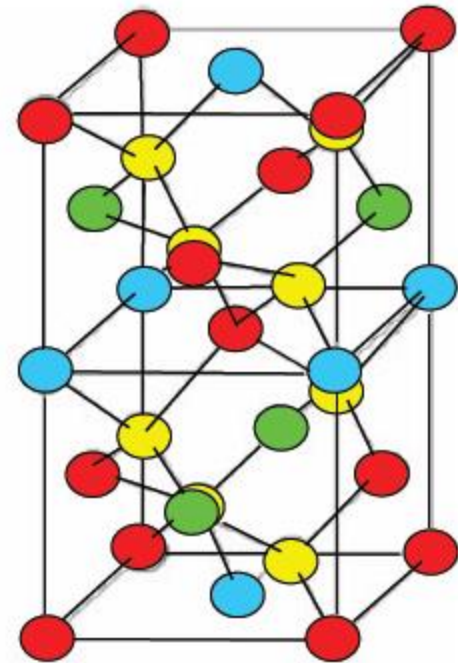
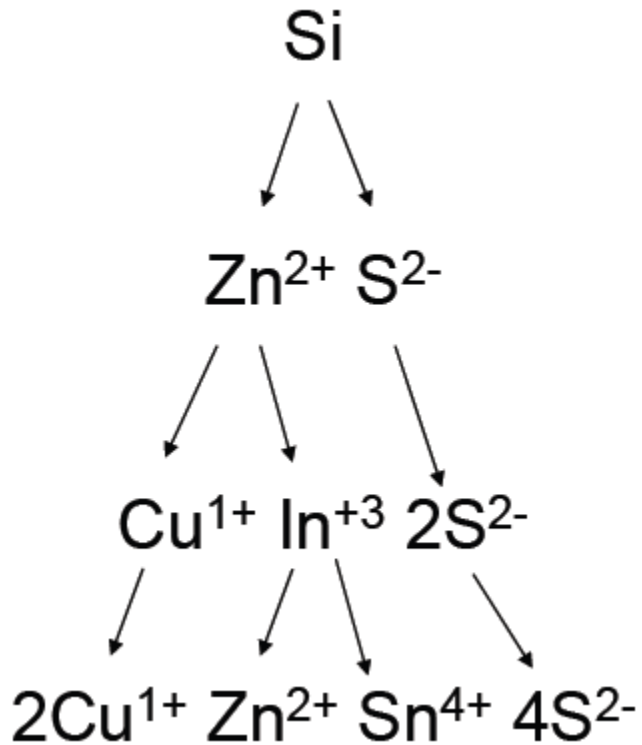
Contacts



Not to scale

Substitution of Indium : The Kesterite alternative $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ 1-1.7 eV

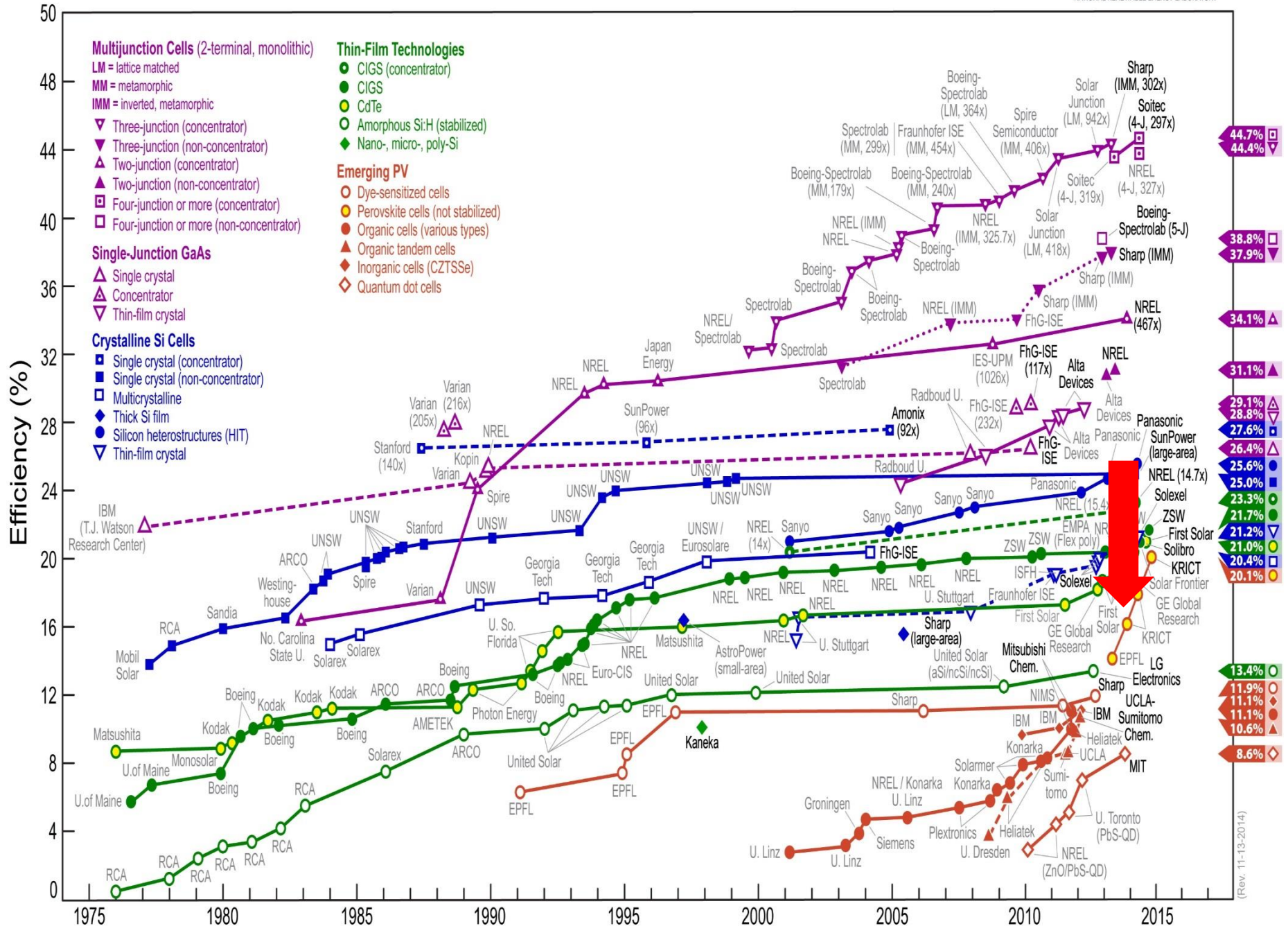
Present efficiency : 12,6%



L'irruption des perovskites

Best Research-Cell Efficiencies

L'irruption de la filière perovskite



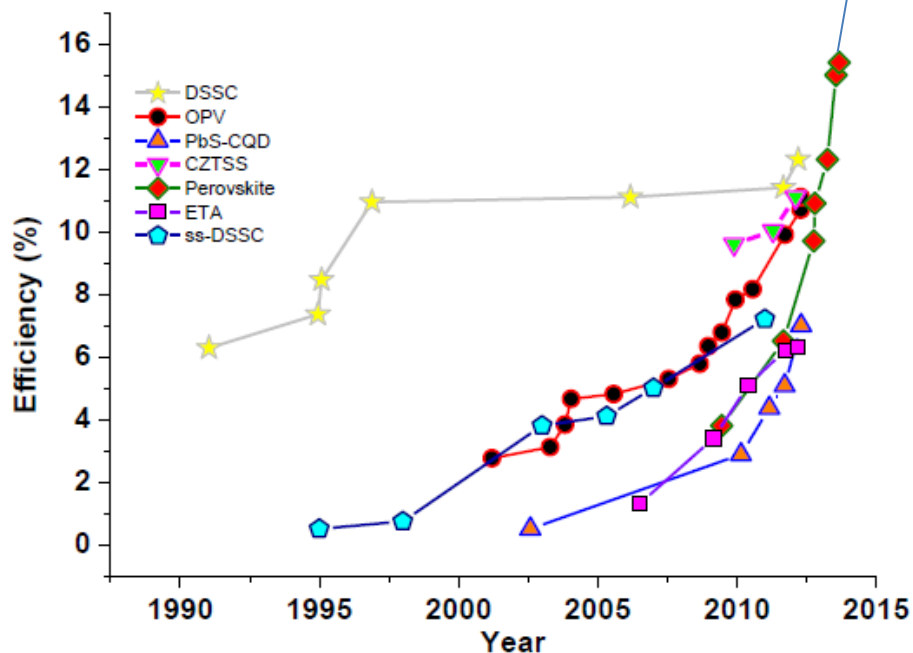
(Rev. 11-13-2014)

L'irruption des cellules organiques et hybrides : le phénomène pérovskite

Préparation à basse température

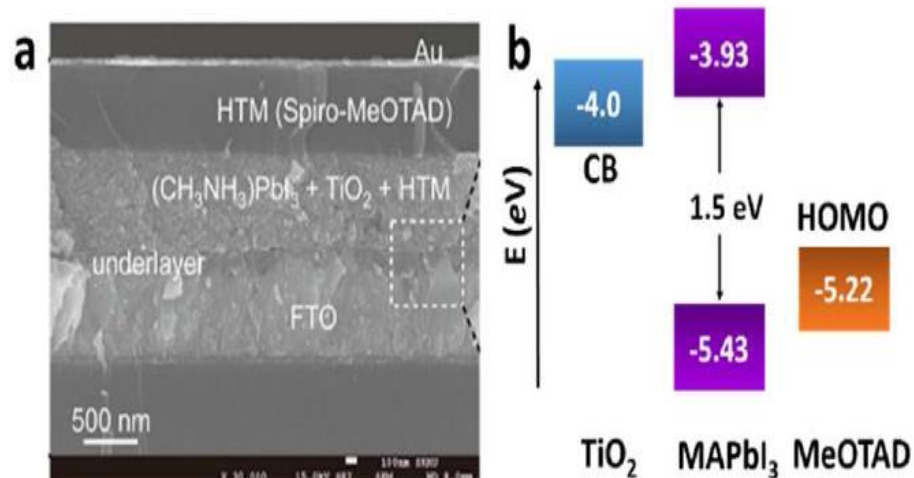
2014

20,8 %
Perovskites
hybrides

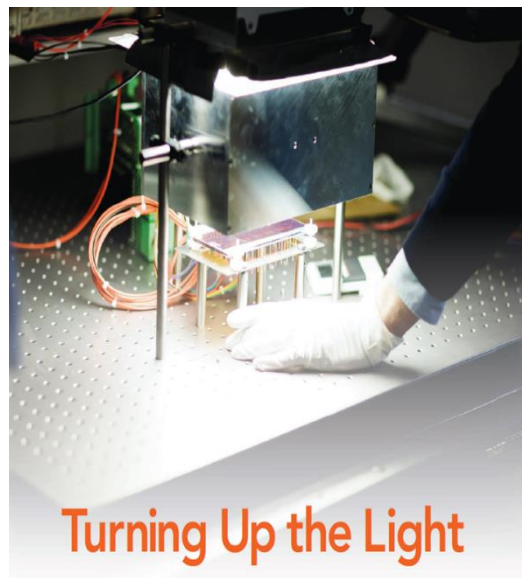


Updated Assessment of Possibilities & Limits for Solar Cells

Pabitra K. Nayak and David Cahen



15 NOVEMBER 2013 VOL 342 SCIENCE www.sciencemag.org



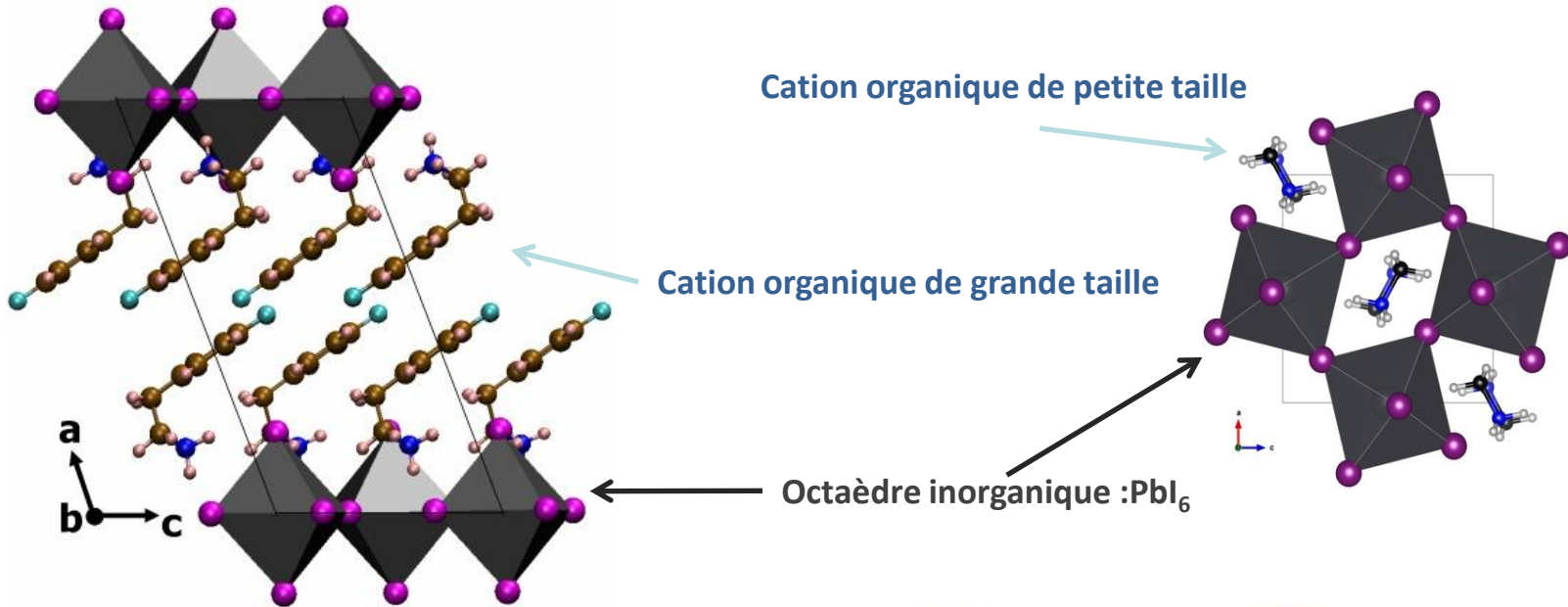
Turning Up the Light

Photovoltaic materials called perovskites work wonders in the lab, but will they shine as commercial technology?

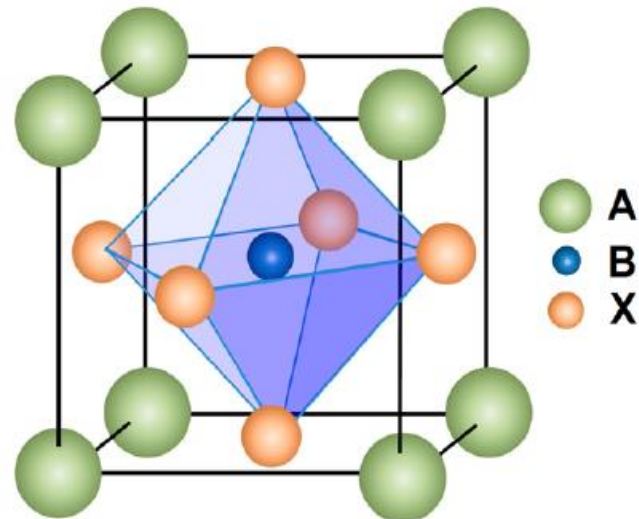


Pérovskites Hybrides

Pérovskites hybrides en couches (2D) Pérovskites hybrides 3D



Réseau idéal inorganique
de type "pérovskite" :

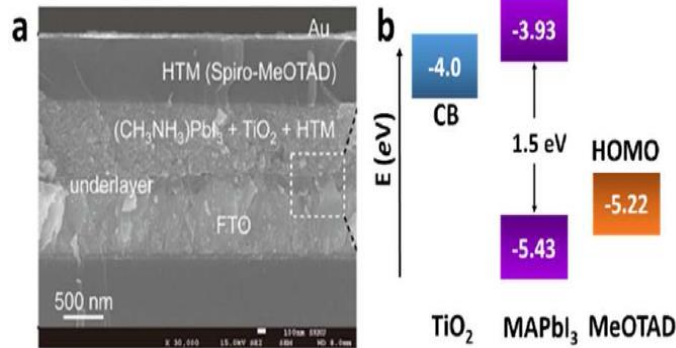


2012 : essor extraordinaire d'une nouvelle filière

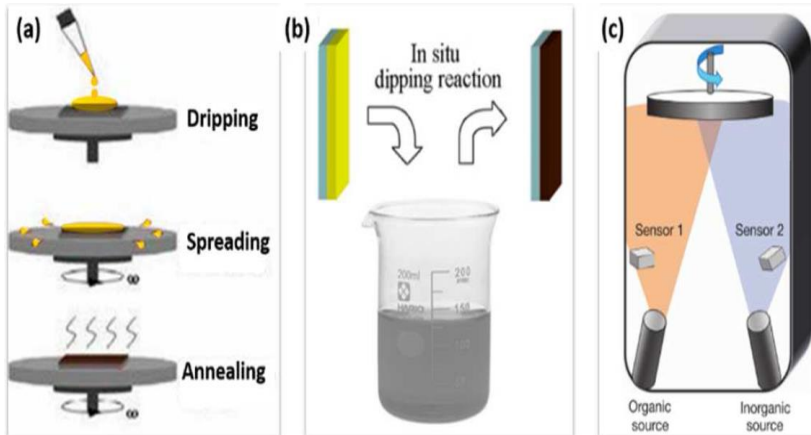
Depuis 2012, évolution des concepts de cellules et des procédés



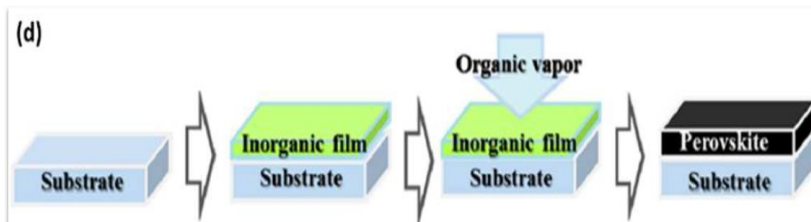
M. Graetzel, Lausan



H. Snath, Oxford



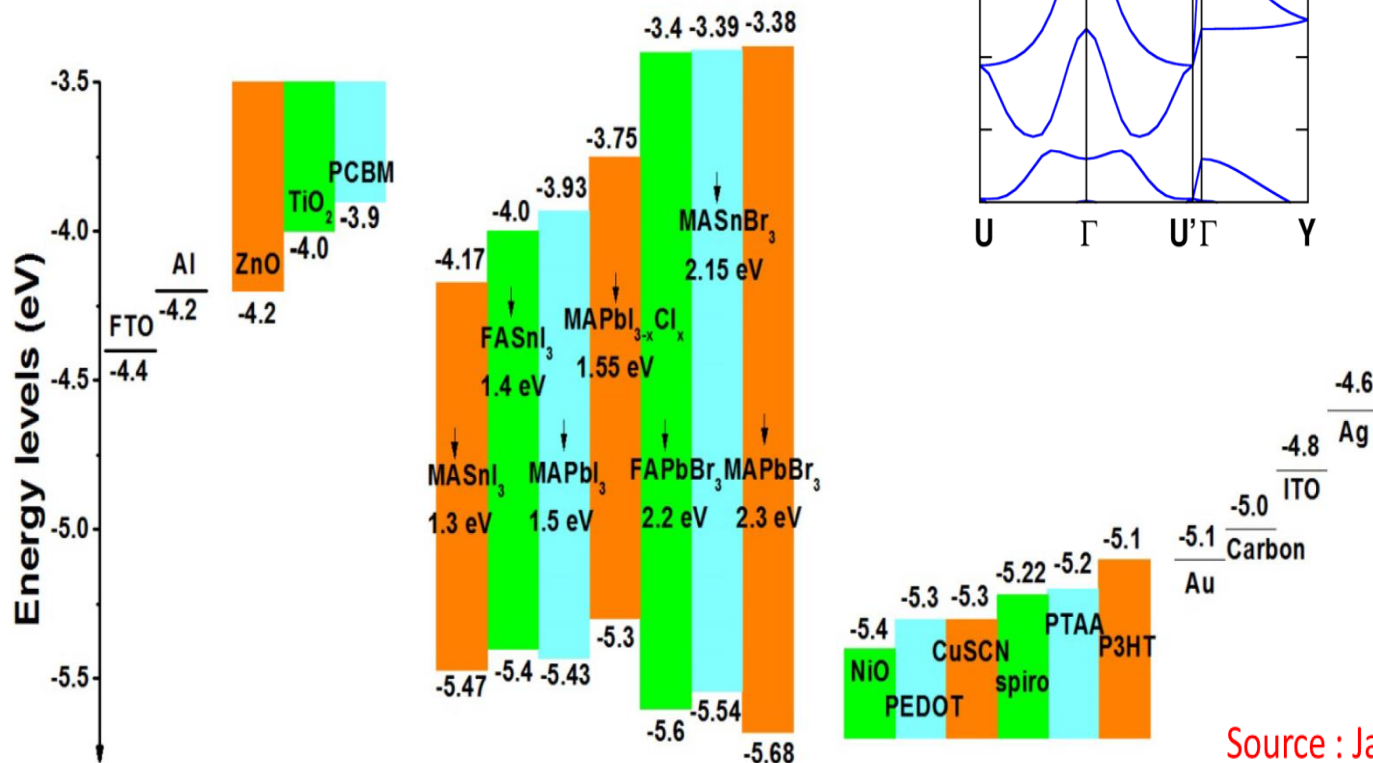
- a) One step precursor deposition
- b) Sequential deposition method
- c) Dual source vapor deposition
- d) Vapor assisted solution process



Source : Jacky EVEN, Foton

Des propriétés physiques exceptionnelles

- a) Structure de bandes favorable $m_e=0.15$, $m_h=1$
- b) Quasi-absence de niveaux électroniques profonds
- c) Exciton quasi-dissocié à la température ambiante
- d) Longueurs de diffusion de 100nm à 1micron
- e) Possibilités d'ingénierie de gap optique



Source : Jacky EVEN, Foton

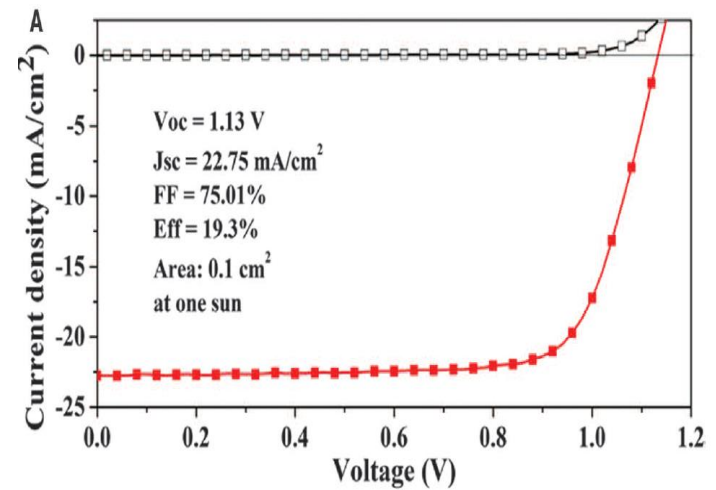
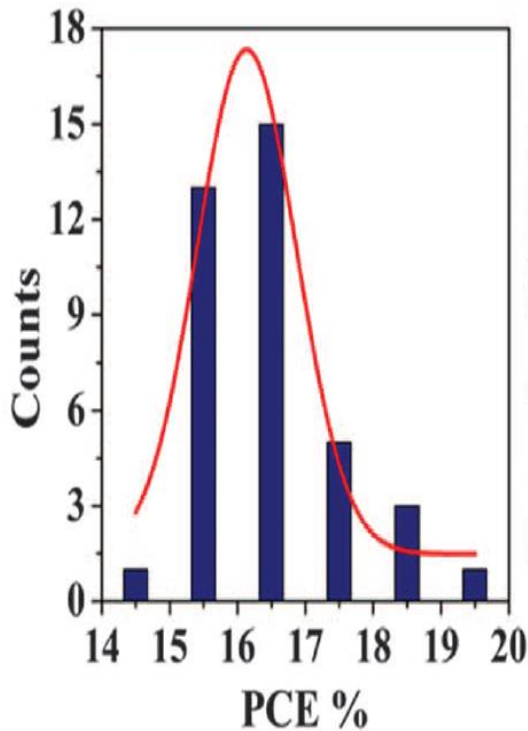
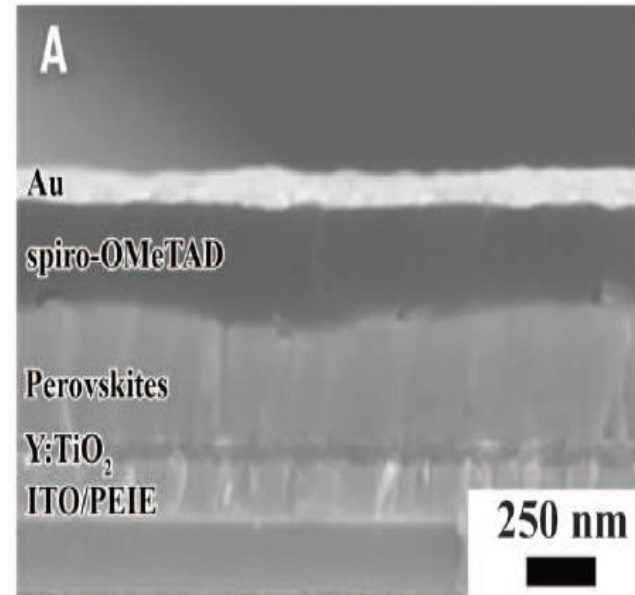
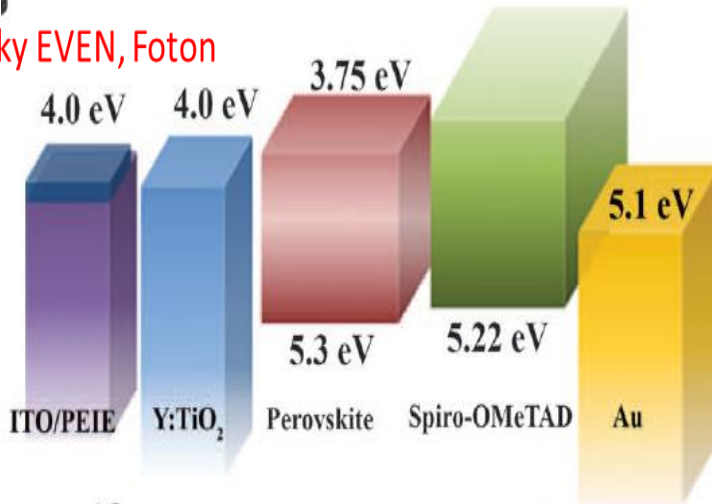
Interface engineering of highly efficient perovskite solar cells

H. Zhou, Qi Chen, G. Li, S. Luo, T. Song, H. Duan, Z. Hong, J. You, Y. Liu, Y. Yang UCLA

Science
2014

$\eta = 19.3\%$

Source : Jacky EVEN, Foton



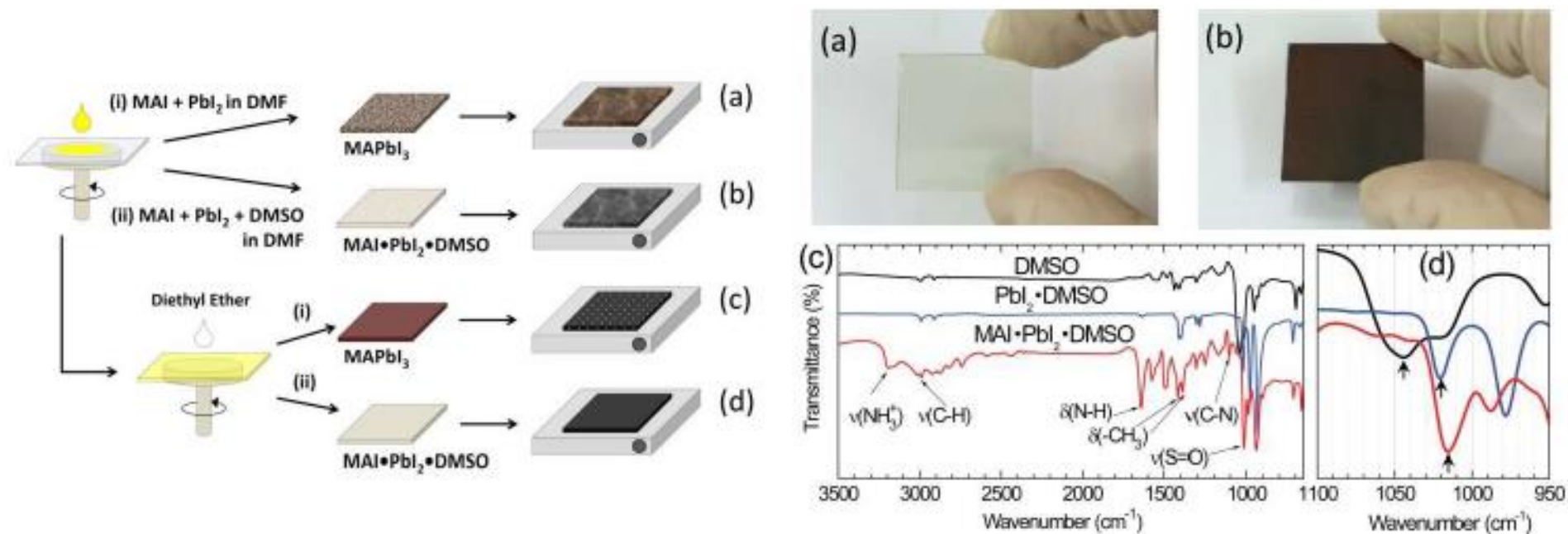
Communication

Highly Reproducible Perovskite Solar Cells with Average Efficiency of 18.3% and Best Efficiency of 19.7% Fabricated via Lewis Base Adduct of Lead(II) Iodide

Namyung Ahn, Dae-Yong Son, In-Hyuk Jang, Seong Min Kang, Mansoo Choi, and Nam-Gyu Park

J. Am. Chem. Soc., **Just Accepted Manuscript** • DOI: 10.1021/jacs.5b04930 • Publication Date (Web): 30 Jun 2015

Downloaded from <http://pubs.acs.org> on July 6, 2015



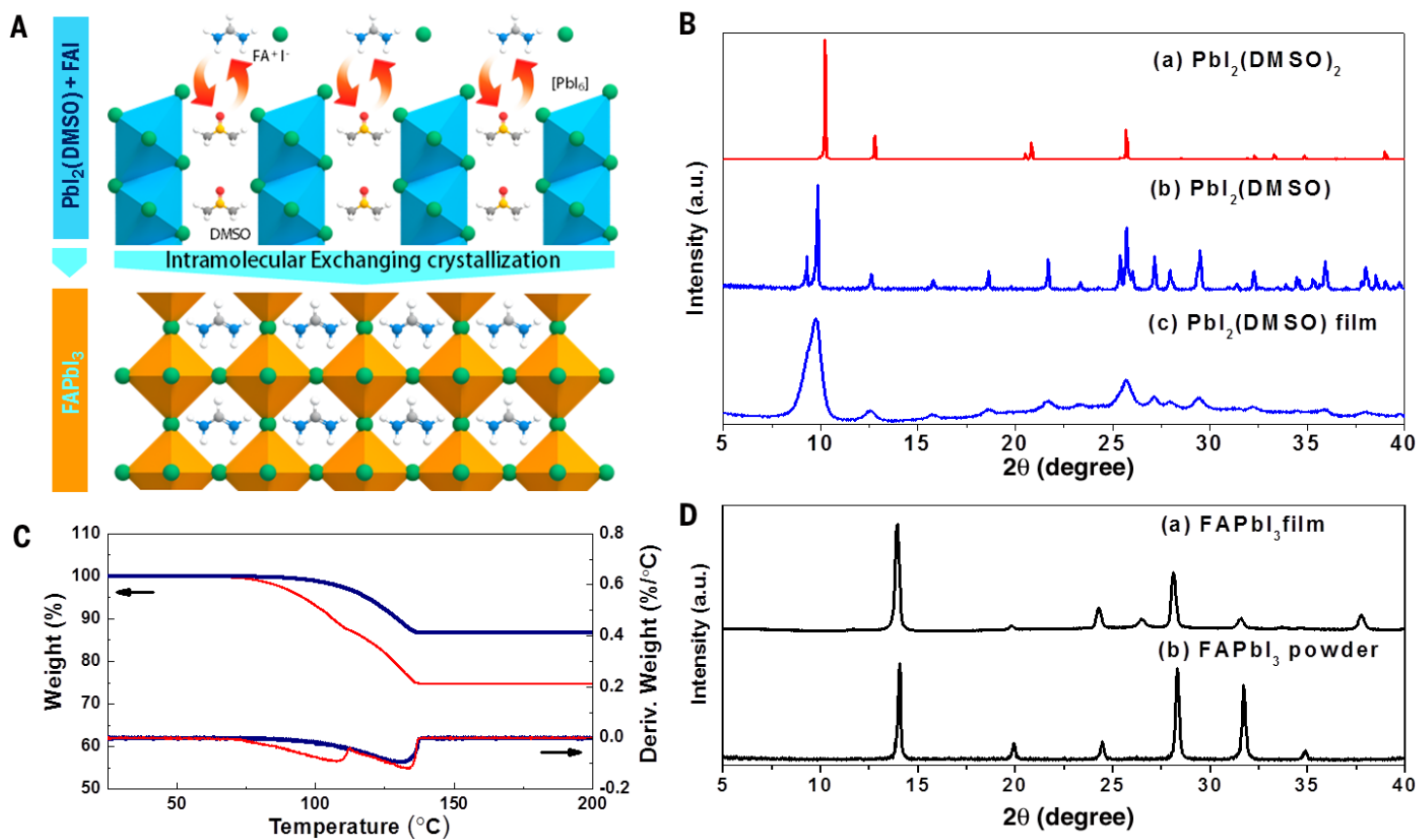
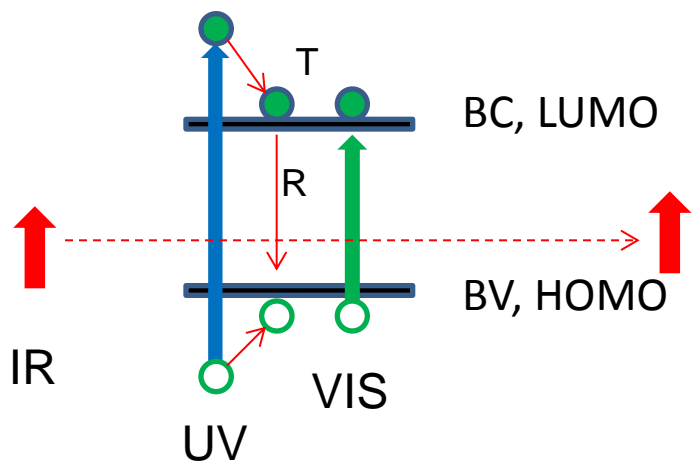



Fig. 1. PbI₂-complex formation and X-ray diffraction. (A) Schematics of FAPbI₃ perovskite crystallization involving the direct intramolecular exchange of dimethylsulfoxide (DMSO) molecules intercalated in PbI₂ with formamidinium iodide (FAI). The DMSO molecules are intercalated between edge-sharing [PbI₆] octahedral layers. (B) XRD patterns of (a) as-prepared PbI₂(DMSO)₂ powders, (b) vacuum-annealed PbI₂(DMSO) powders, and (c) as-deposited film on fused quartz substrate using PbI₂(DMSO) complex solution. (C) TGA of PbI₂(DMSO)₂ (red line) and PbI₂(DMSO) (dark blue line). (D) XRD patterns of (a) as-formed film of FAPbI₃ by IEP, and (b) FAPbI₃ powder.

Vers les très hauts rendements

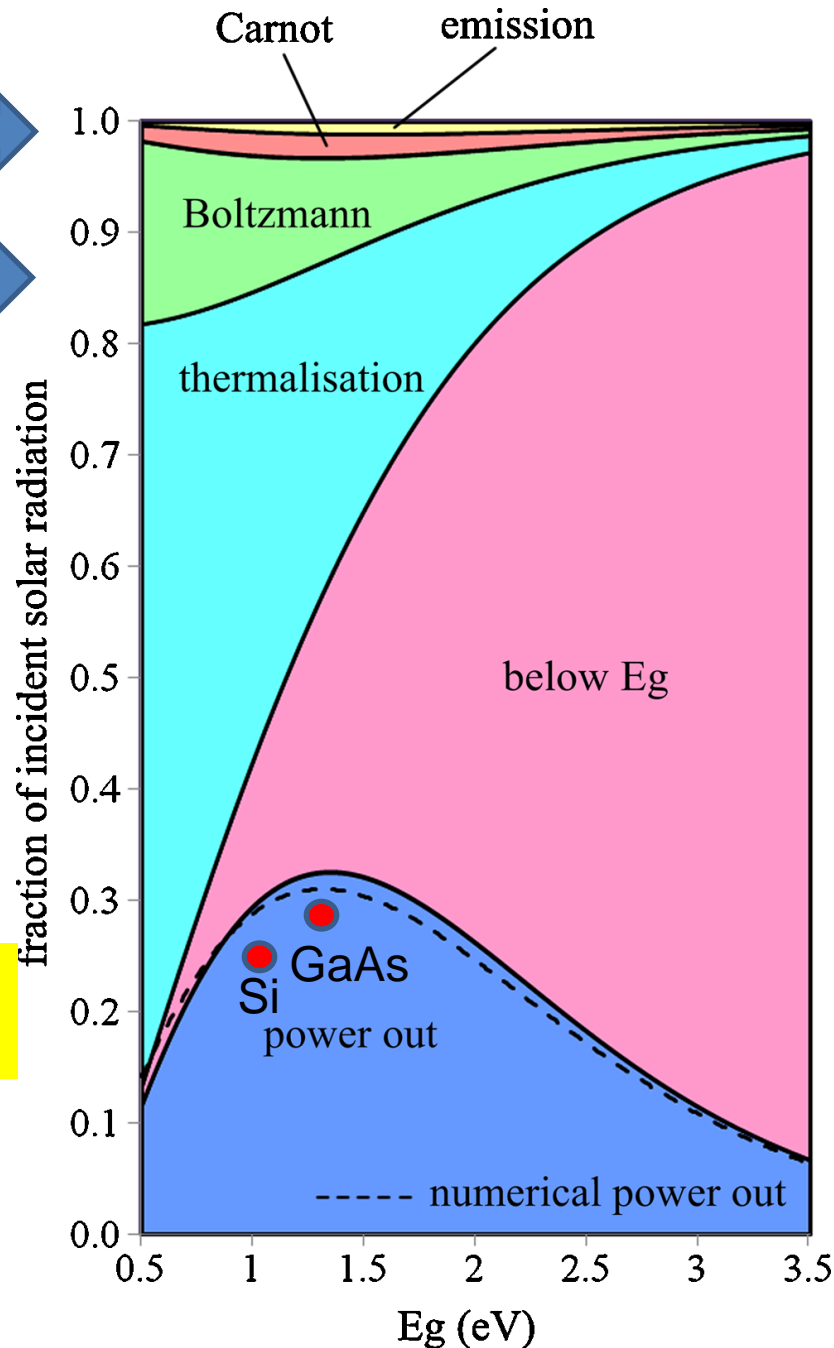
Limite de Carnot (95%) 

Limite théorique (85%) 

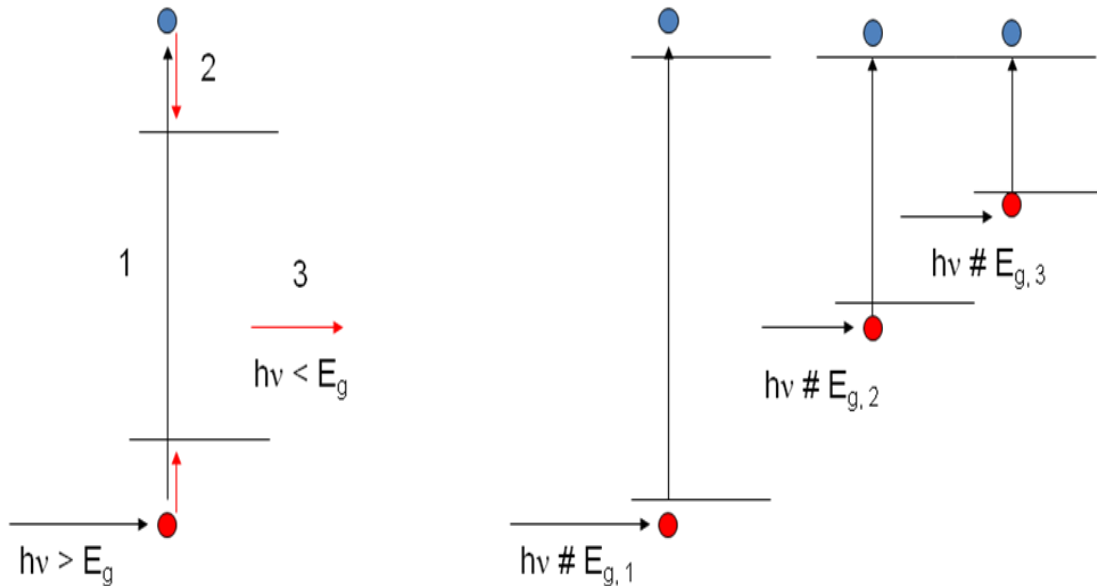


Limite de conversion pour une cellule Solaire classique (Shockley Queisser) 

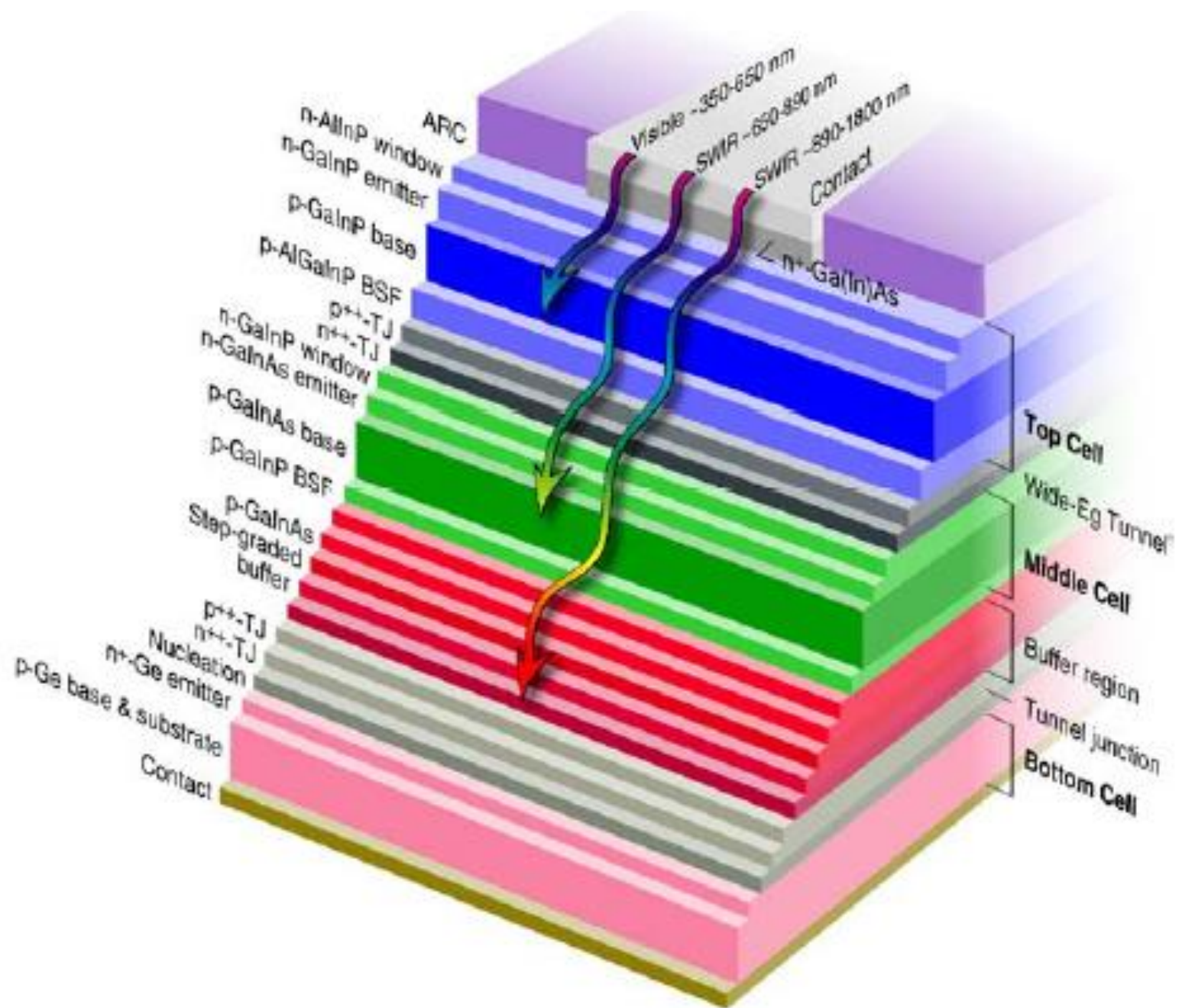
T : perte d'énergie par thermalisation
R : perte d'énergie par recombinaison



Un concept établi : les multijonctions

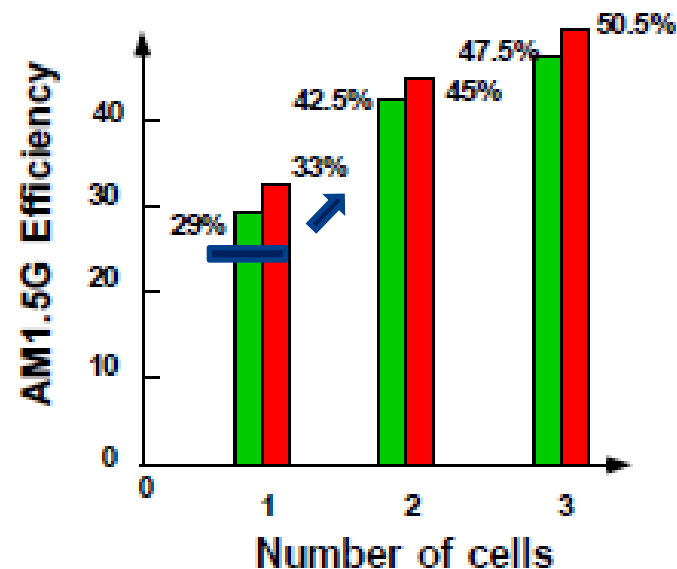
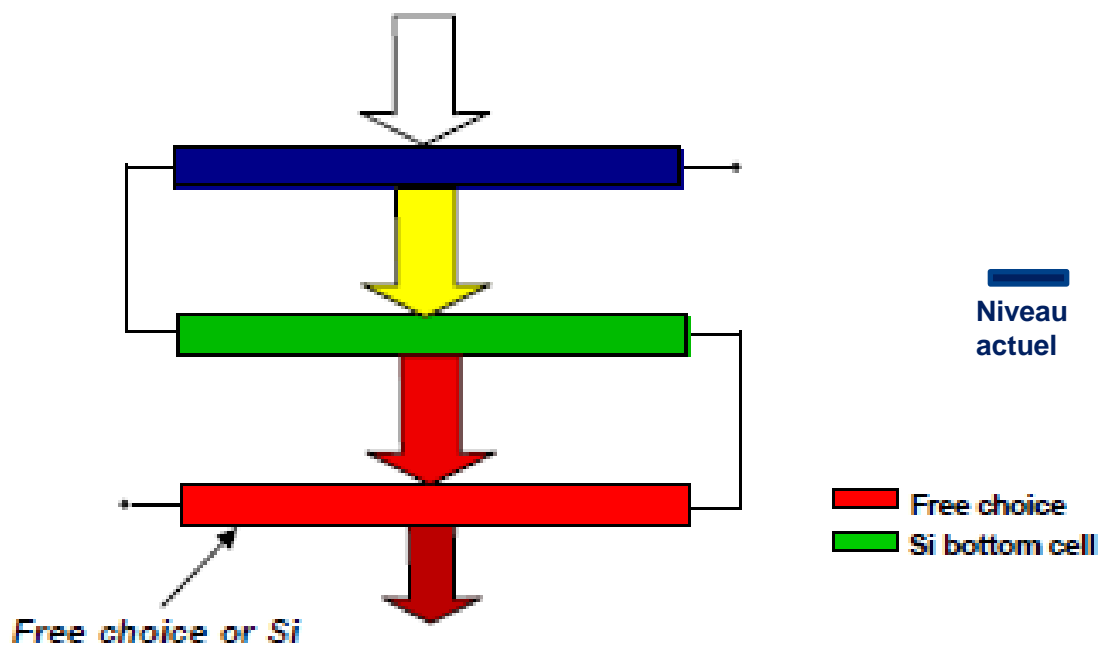


Rendement record : 46 % (2014)
Soitec-Fraunhofer ISE (4 jonctions)



Vers des modules standards à 30 % de rendement dans les années à venir ? (> 2020)

La voie des cellules Tandem basée sur les technologies actuelles Si ou CIGS



Approches à plus long terme (> 2030) :

Nouveaux concepts très hauts rendements (>50%) :

Cellules à conversion de photons (photonique) , cellules à porteurs chauds, plasmonique (confinement des photons)



Cite this: DOI: 10.1039/c4ee03322a

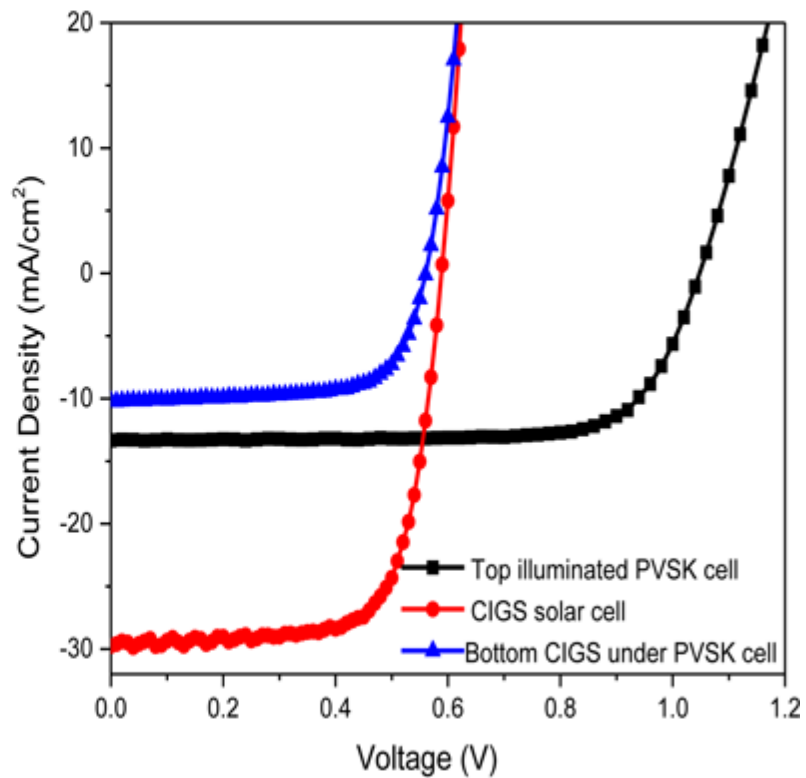
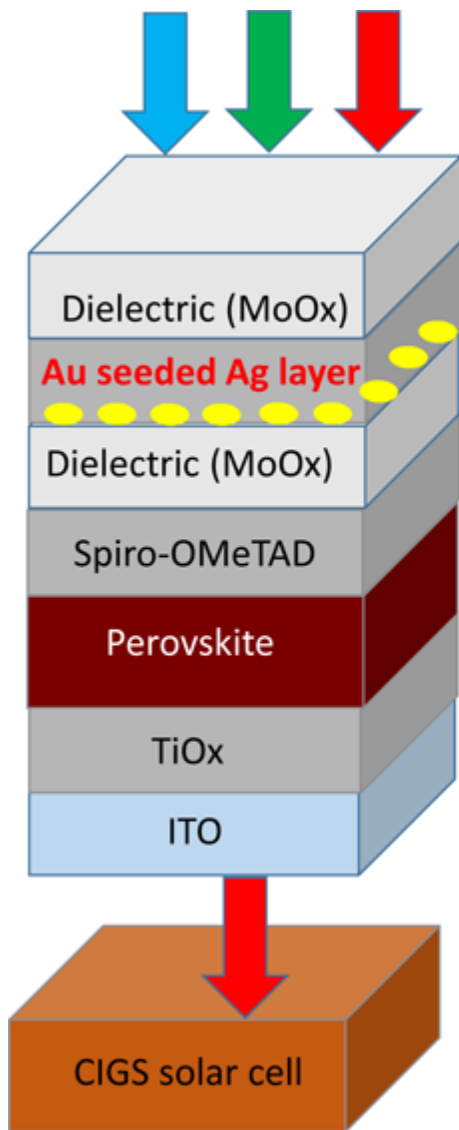
Semi-transparent perovskite solar cells for tandems with silicon and CIGS†

Colin D. Bailie,^{‡a} M. Greyson Christoforo,^{‡b} Jonathan P. Mailoa,^c Andrea R. Bowring,^a Eva L. Unger,^a William H. Nguyen,^d Julian Burschka,^{§e} Norman Pellet,^e Jungwoo Z. Lee,^c Michael Grätzel,^e Rommel Noufi,^f Tonio Buonassisi,^c Alberto Salleo^a and Michael D. McGehee^{*a}

Received 21st October 2014

Accepted 22nd December 2014

DOI: 10.1039/c4ee03322a





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Semi-transparent perovskite solar cells for tandems with silicon and CIGS†

Colin D. Bailie,^{‡a} M. Greyson Christoforo,^{‡b} Jonathan P. Mailoa,^c Andrea R. Bowring,^a Eva L. Unger,^a William H. Nguyen,^d Julian Burschka,^{§e} Norman Pellet,^e Jungwoo Z. Lee,^c Michael Grätzel,^e Rommel Noufi,^f Tonio Buonassisi,^c Alberto Salleo^a and Michael D. McGehee^{*a}

Received 21st October 2014

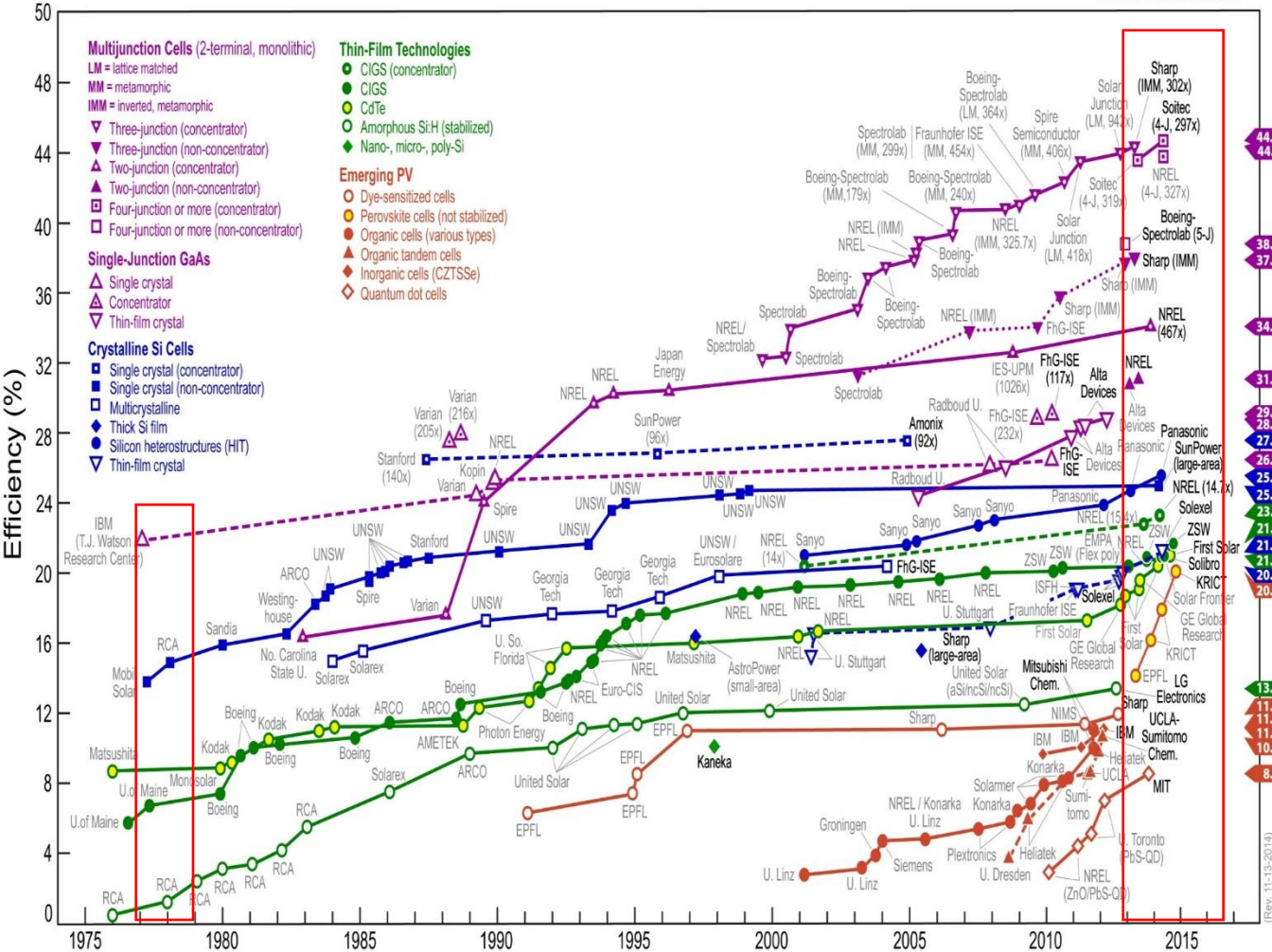
Accepted 22nd December 2014

DOI: 10.1039/c4ee03322a

Perspectives

Panorama complet de l'évolution des technologies photovoltaïques 35 ans de recherches au niveau international

Best Research-Cell Efficiencies



1978 (ma thèse)

2015

2050

Conclusions

- Le photovoltaïque est maintenant une **source d'énergie majeure et abondante** pour la transition énergétique et la lutte contre le changement climatique
- Foisonnement des recherches-nouveaux concepts-nouveaux usages → complémentarité entre les technologies
- Développement de nouveaux matériaux de plus en plus complexes, importance des interfaces
- Importance d'améliorer les connaissances fondamentales : composition-structure-propriétés
- Importance de la chimie du solide (dopage, position des bandes, diagrammes de phase...)
- Matériaux inorganiques, organiques et hybrides



<http://www.photoniques.com/articles/photon/pdf/2015/05/photon201578p23.pdf>

Silicium, couches minces, pérovskites, photonique :
de nouvelles avancées de la recherche sur les cellules photovoltaïques

Un bon signe pour la COP 21

Daniel LINCOT^{1,2}, Stephane COLLIN³,
Jacky EVEN⁴, Jean-Paul KLEIDER⁵