UMR 9006

IPVF

INSTITUT PHOTOVOLTAÏQUE D'ILE-DE-FRANCE

IPVF and recent progress in photovoltaics

Jean-François Guillemoles[1,2]

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cnrs

ÉCOLE POLYTECHNIQUE

IP PARIS

Chimie Paris ParisTech

PSL

NanoSaclay
Laboratoire d'Excellence en Nanosciences et Nanotechnologies

Palaiseau, 19/09/2019

ITE IPVF

200
RESEARCHERS ON THE LONG TERM

7800
m² BUILDING

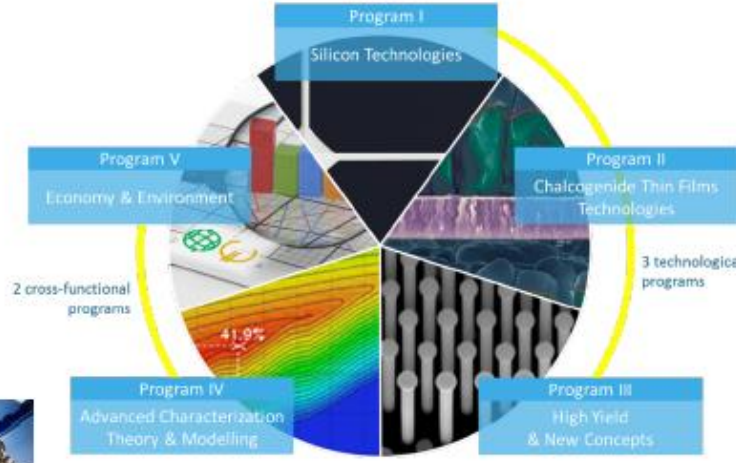
Founding Members

EDF · TOTAL · CNRS · X · AIR LIQUIDE Creative Oxygen · HORIBA JOBIN YVON · RIBER

A French Institute for Energy Transition (ITE)

INVESTISSEMENTS D'AVENIR · ANR

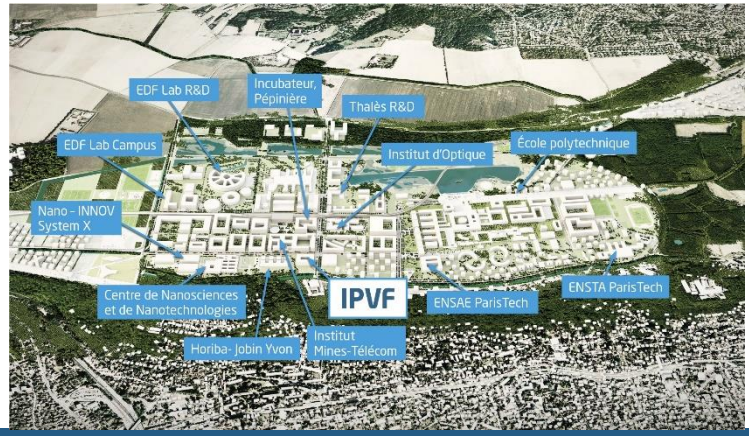
Scientific program



Experimental Research Platform

IPVF activities and equipment spread across partner laboratories

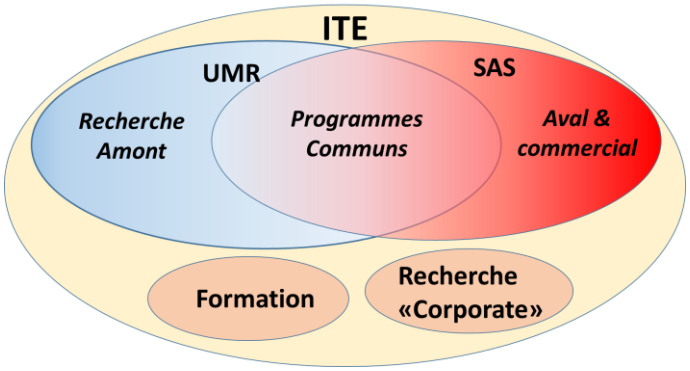
2017



UMR IPVF

- Partnership between actors of R&D & CNRS
  - Object oriented research : photovoltaics
  - Fundamental research on key competences

Created 1/06/2018



COTUTELLES

IPVF INSTITUT PHOTOVOLTAÏQUE D'ILE-DE-FRANCE

cnrs

EDF

TOTAL

Air Liquide creative oxygen

Chimie Paris ParisTech

Permanent Staff :

- **Academia: 12**
- **Industry : 6**
- **Doc/Pdocs: 12-18**

CONTRIBUTIONS

• **Proofs of concept** • **Advanced Characterisations** • **Process development** • **Expertises**
• **Patenting** • **Development & prototyping**• **Training, teaching, scientific popularization**

Becquerel 2.00

200th Edmond Becquerel's birthday

1839: discovery of photovoltaic effect

1939: CNRS 80th

COMPTE RENDU

DES SÉANCES

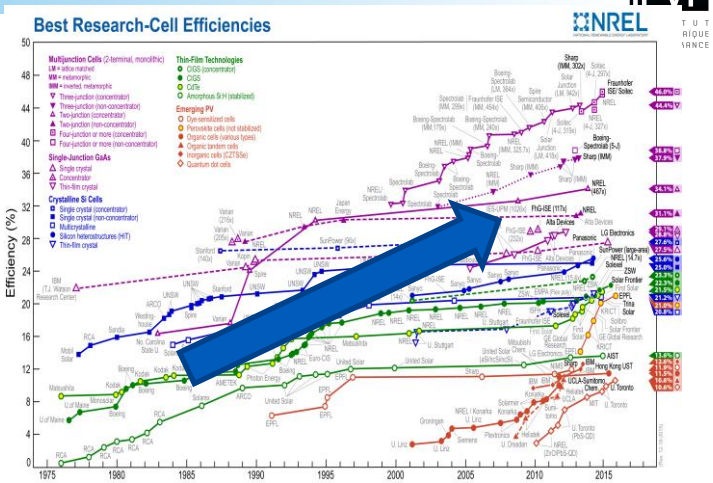
DE L'ACADÉMIE DES SCIENCES.

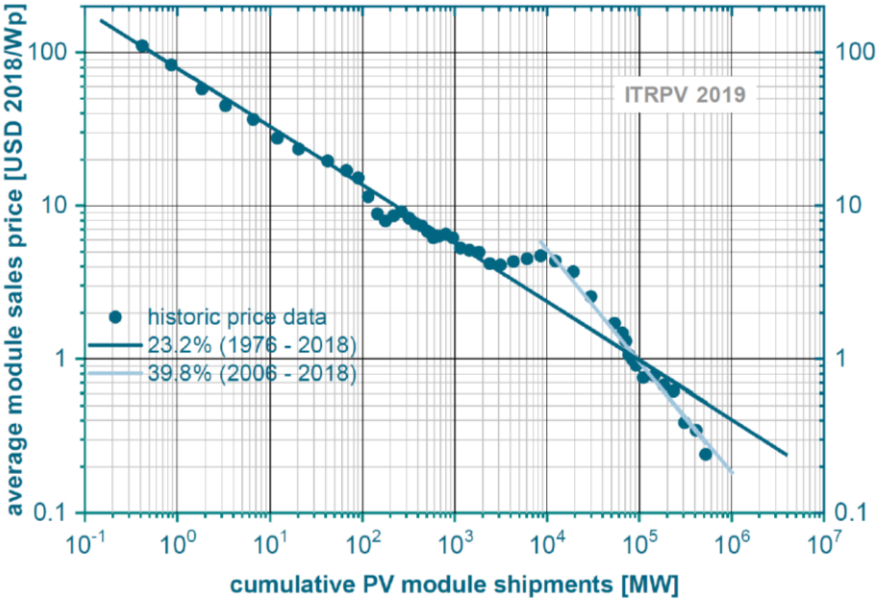
SÉANCE DU LUNDI 4 NOVEMBRE 1839.

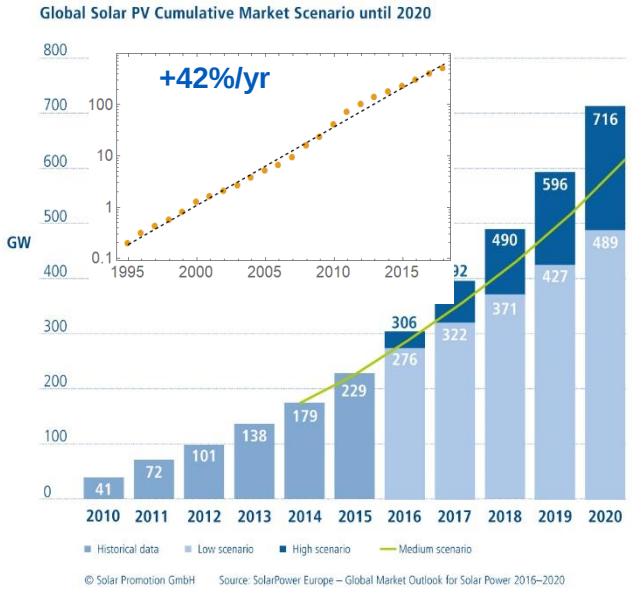
PRÉSIDENCE DE M. CHEVREUL.

Context

- Expanding field
  - PV electricity 2% ww
  - > 500 GW installed
  - Modules ~ 20% eff , <0.3 €/W
  - 2 €/MWh







Challenges & Highlights

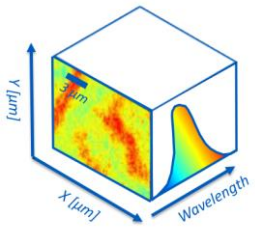
- Aligned with societal challenges
  - New materials and processes for lower cost and higher performance
  - Reliable & sustainable at TW scale

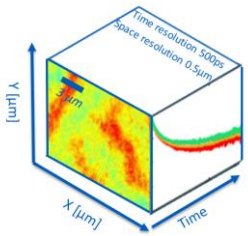
un rendement > 30%

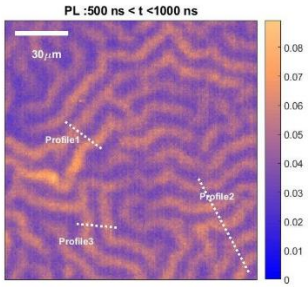
3 pour un prix < 30 c$/Wc

à l'horizon 2030

- Pushing the limits
  - Ultimate efficiencies
  - Advanced materials
  - Advanced diagnostics
    - Hyperspectral Imaging for charge transport
    - Synchrotron techniques for interfaces (MOPGA)







ARTICLES nature energy

Quantitative experimental assessment of hot carrier-enhanced solar cells at room temperature

Dac-Trung Nguyen[1], Laurent Lombez[1,2]*, François Gibelli[1,2], Soline Boyer-Richard[3], Alain Le Corre[3], Olivier Durand[3] and Jean-François Guillemoles[1,2]

nature COMMUNICATIONS

ARTICLE

OPEN

Quantitative optical assessment of photonic and electronic properties in halide perovskite

Adrien Bercegol[1,2], Daniel Ory[1,2], Daniel Suchet[2,3], Stefania Cacovich[2], Olivier Fournier[1,2], Jean Rousset[1,2] & Laurent Lombez[2,3]

ACS Energy LETTERS

Interface Design for Metal Halide Perovskite Solar Cells

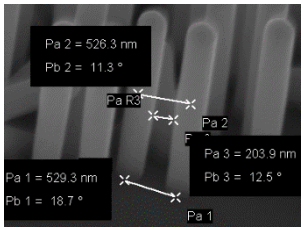
Philip Schulz

CNRS-Institut Photovoltaique d'Ile de France (IPVF), UMR 9006, Palaiseau, France
National Renewable Energy Laboratory, Golden, Colorado 80401, United States

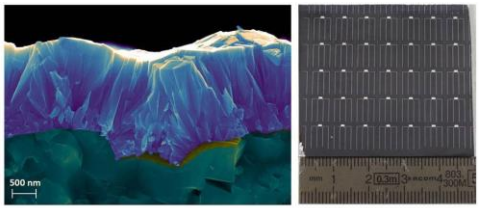
- Training the next generation

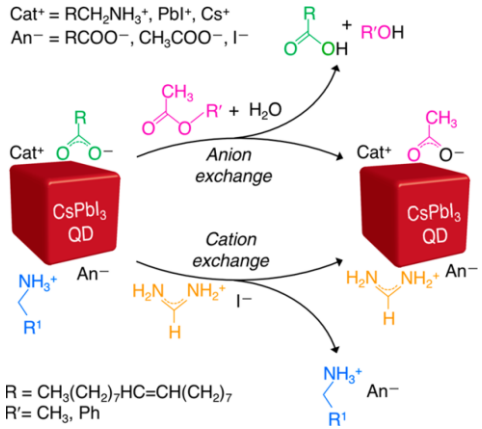
Knowledge and know-how basis : Elaboration

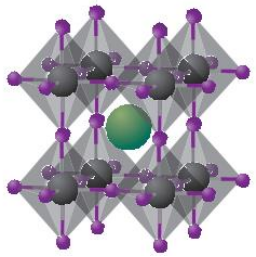
- Material growth Processes
  - Coevaporation
  - ALD
  - Solution chemistry (CBD, Electrodeposition)
  - Sputtering



- Materials base
  - Oxides: ZnO, TiO2, ZnMgO, CuOx, …
  - Chalcogenides: (Cd,Zn)S, (In,Ga)Sx, CIGS, CZTS, CdTe,CuSx …
  - Perovskites (halides)
  - Organochemistry
  - III-V
  - Metals

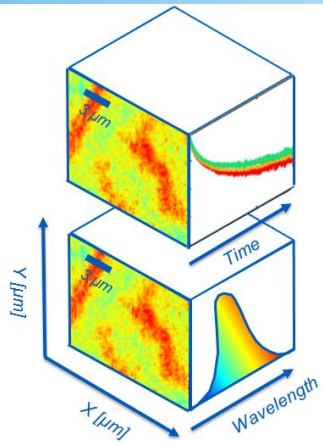






Knowledge and know-how basis: Characterization & Modeling

- Optoelectronic
  - Luminescence Imaging (λ, t)
  - Access to transport parameters
  - Commercial applications



ARTICLE

https://doi.org/10.1038/s41467-019-09527-w OPEN

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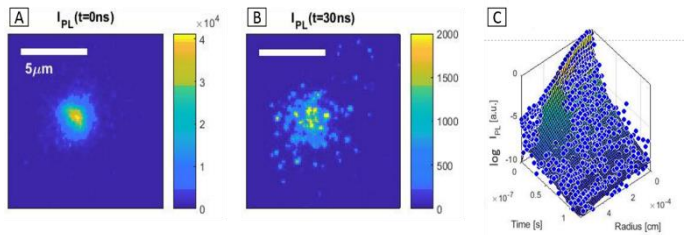
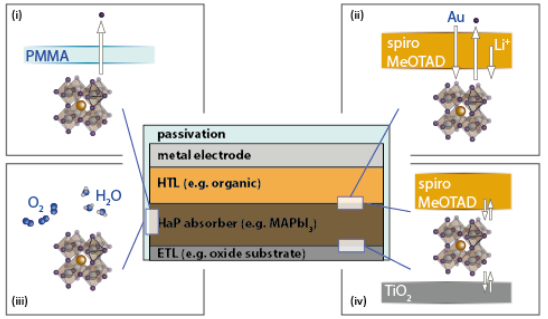


- Interfaces
  - Energetics at interface
  - Interface design, Interface treatments
  - Synchrotron and XPS



P. Schulz, D. Cahen, A. Kahn. *Chem. Rev.* **2019**

J. A. Christians, P. Schulz, […] J. M. Luther,*Nature Energy* **2018**

- Fundamental studies
  - New solar cell concepts (photonics, Hot carriers)
  - Physics of PV conversion (Ratchets)
  - Physics of materials (e.g. Direct c-Si)

nature photonics

Comment | Published: 24 July 2

Guide for the
Queisser moc

Jean-Francois Guillemoles, Th

Nature Photonics **13**, 501–505 (2

ARTICLES

https://doi.org/10.1038/s41560-018-0106-3

nature energy

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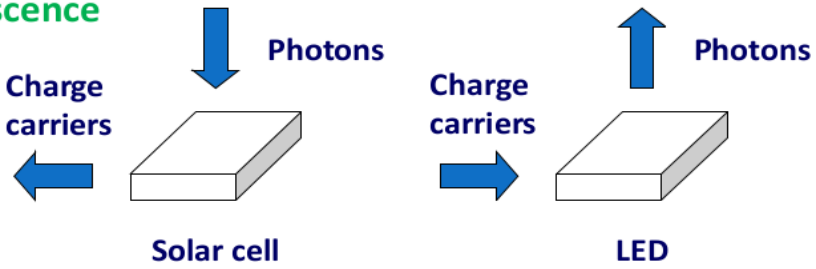
Reciprocities in PV conversion

Reciprocity PV/LED :

Electro-Luminescence



$$\Phi_{EL}(E) \approx EQE(E) \frac{1}{4\pi^2 \hbar^3 c_0^2} E^2 \exp\left(\frac{qV - E}{kT}\right)$$

Absorption & Emission, Injection & Collection

A long list of reciprocities:

Gustav Kirchhoff 1860, Van Roesbroek 1954, Wurfel 1980, Donolato 1985, Araujo 1994, MA Green 1997, U. Rau 2007, Wong 2012, JJ. Greffet 2018, …

Imaging Photogenerated carrier transport

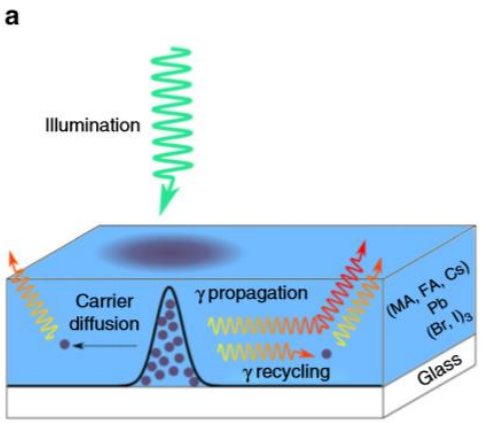
nature COMMUNICATIONS

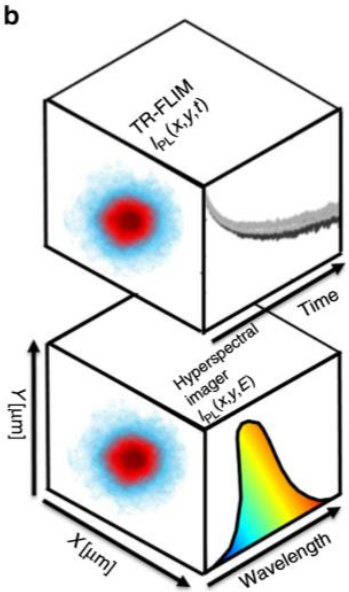
photonic and electronic properties in halide perovskite

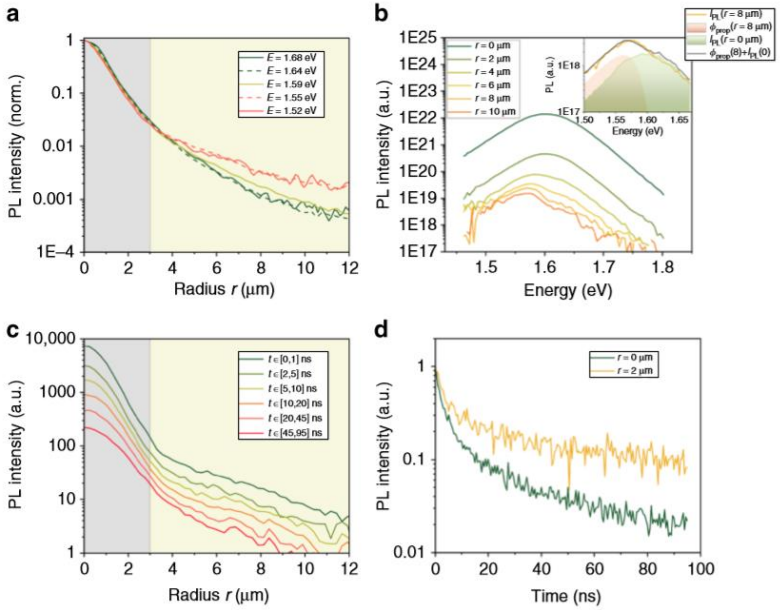
Adrien Bercegol, Daniel Ory, Daniel Suchet, Stefania Cacovich, Olivier Fournier, Jean Rousset & Laurent Lombez

Nature Communications **10**, Article number: 1586 (2019) | Download Citation

- What is the true diffusion length in perovskites?
- Sorting out Photon Recycling from photon propagation and carrier diffusion

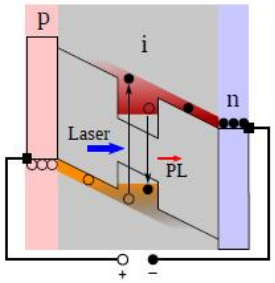


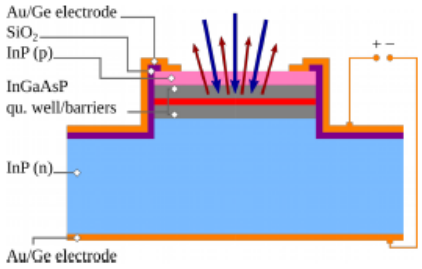




Non isothermal cells and generalization

- A case study: hot carrier solar cells





- **Small mesa devices (µcells)**
  - ✓ **Low Rs, Heat extraction**
  - ✓ **Linear Jsc up to 10^5 suns**
- **Very thin solar cell (250 nm)**
- **> 600 K electrons @ >15000 suns**

ARTICLES
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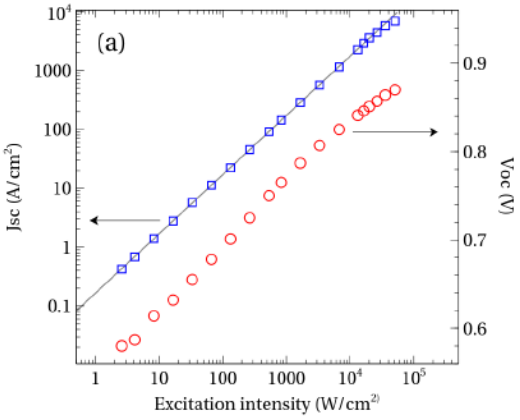
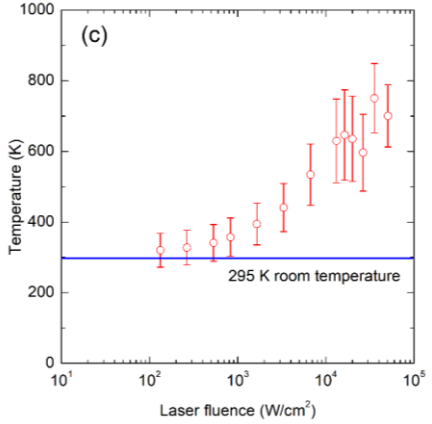
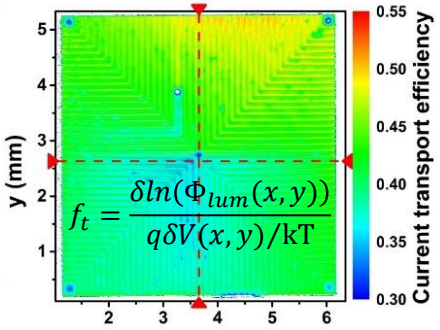


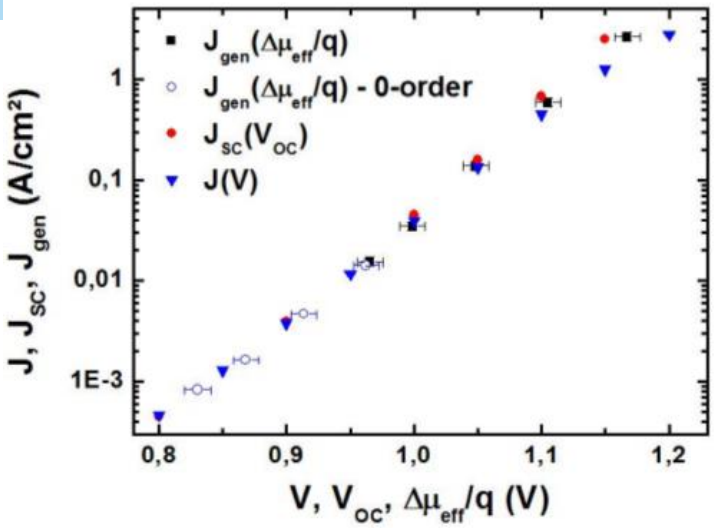


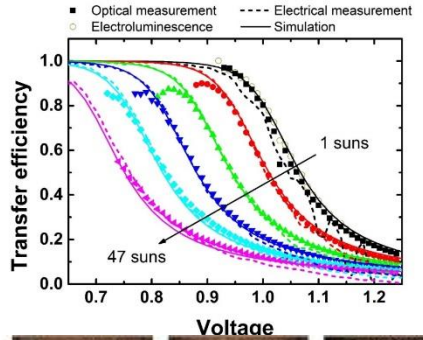
A. Lebris et al., Energy Environ. Sci., 2012
Trung Nguyen et al. Nature Energy, 2018

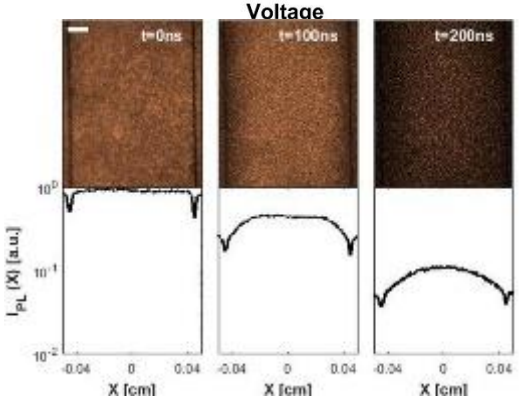
Caracterization methods

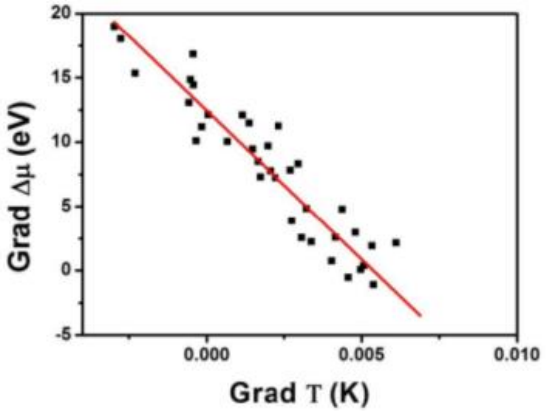
- Contactless I-V and conversion eff.
- Carrier collection
- Thermal effects
  - ✓Including separate information o electrons and holes
- Time resolved maps
  - ✓TR-FLIM
  - ✓MPL











F. Gibelli et al. Phys rev Appl. (2016)

Perspectives

- The basics : innovative routes to higher performance at lower cost

- Next challenges in PV conversion
  - ✓Sustainability
  - ✓Reliability of new technologies
  - ✓ Integration and usages

- Beyond solar to electricity: solar to fuels

…and to work with you all on these challenges, folks!

Collaboration Network

A French Institute for Energy Transition

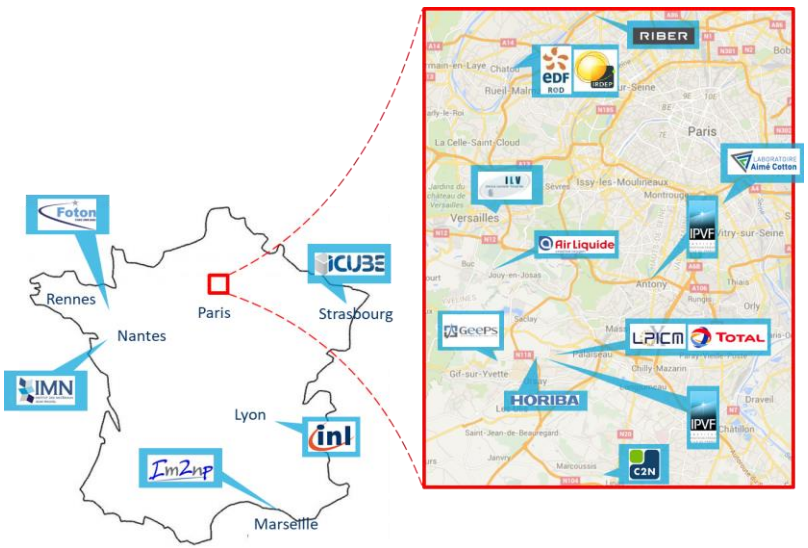
IPVF
INSTITUT PHOTOVOLTAÏQUE D'ILE-DE-FRANCE

National

FedPV
Fédération de recherche PhotoVoltaïque

INVESTISSEMENTS D'AVENIR

Agence Nationale de la Recherche
ANR



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