FROM RESEARCH TO INDUSTRY

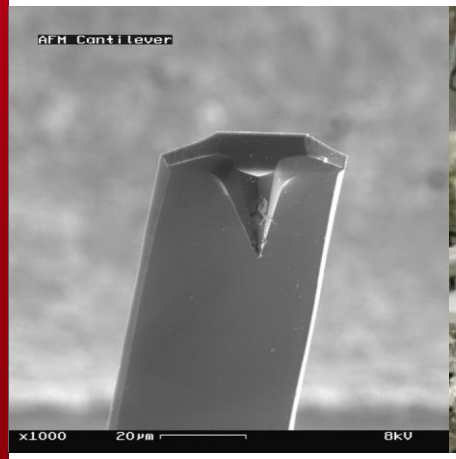
cea tech

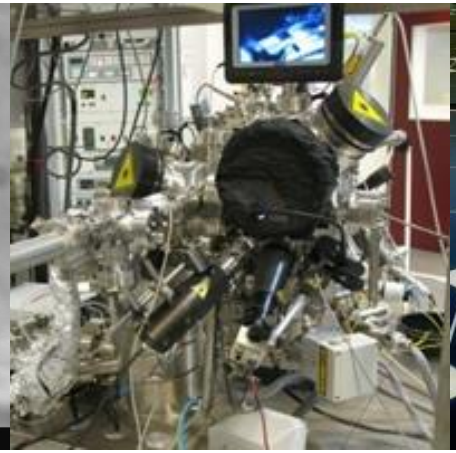
leti

IMAGING THE MULTI-TEMPORAL DYNAMICS OF PHOTOCARRIERS AT THE NANOMETER SCALE

Pablo Fernández Garrillo[1,2,3], Lukasz Borowik[1,2], Florent Caffy[1,3], Renaud Demadrille[1,3], Benjamin Grévin[1,3]

[1] Univ. Grenoble Alpes, F-38000 Grenoble, France
[2] CEA, LETI, MINATEC Campus, F-38054 Grenoble, France.
[3] CEA, CNRS, INAC-SPrAM, F-38054 Grenoble, France.



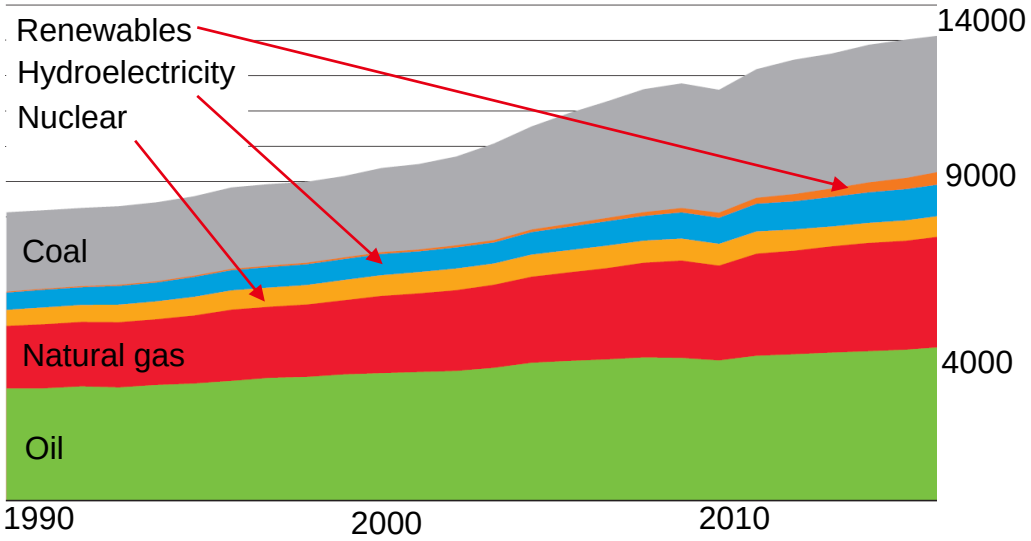


INSTITUT NANOSCIENCES ET CRYOGÉNIE

WHY SOLAR ENERGY?

World energy consumption Million tonnes oil equivalent

Source: BP Statistical Review of World Energy June 2016

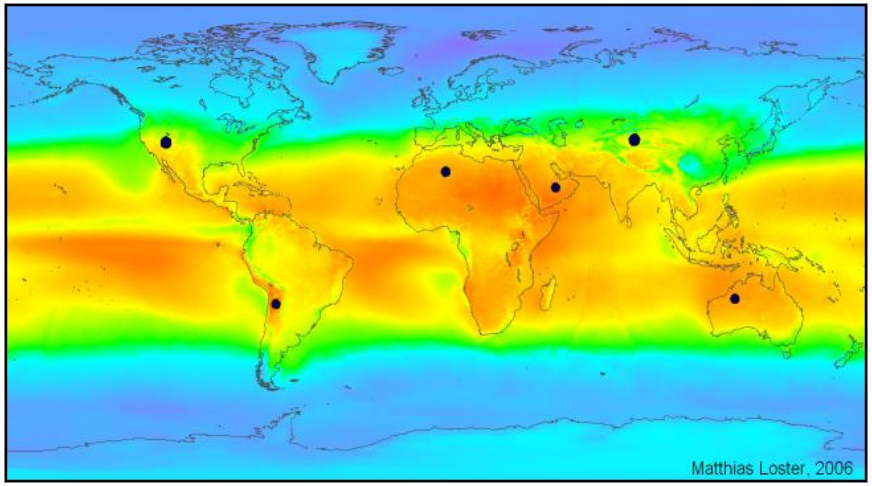


Since 1992 worldwide PV capacity doubled up each 2.4 years

Source: Statistical Review of World Energy – Historical Data Workbook BP

Worldwide PV capacity grew by 32% last year only

Source: www.solarpowereurope.org/insights/new-global-market-outlook-2016/



Σ● = 18 TWe

Average Insolation

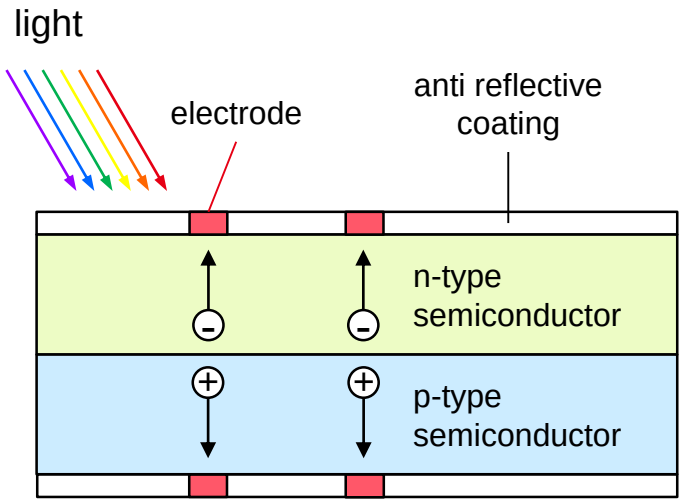
Black dots represents the theoretical area sufficientient to suply the world's total energy needs of 18 TW with solar power

Source: Matthias Loster, 2010 http://www.ez2c.de/ml/solar_land_area/

CHARACTERIZATION OF SOLAR CELLS

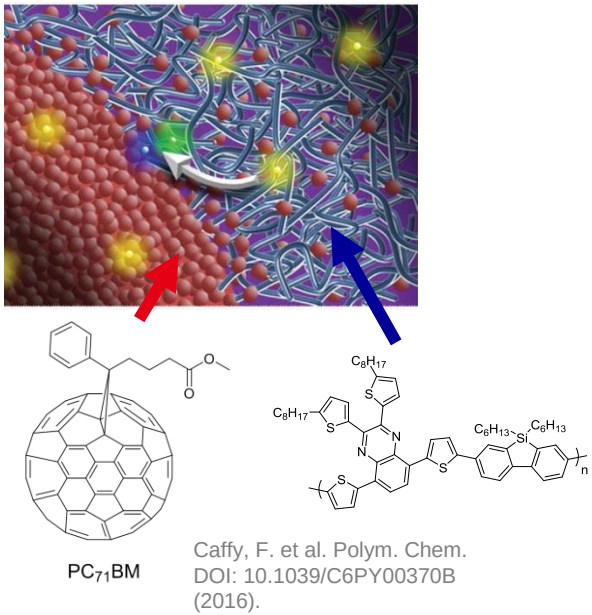
PHYSICAL KEY PARAMETERS

- Carrier mobility μ
- **Photo-carrier dynamics τ**
- Absorption coefficient α / Gap E_g



WHY τ IS IMPORTANT?

- Limits the collection of photo-generated charges by the electrodes of the solar cell.



Caffy, F. et al. Polym. Chem. DOI: 10.1039/C6PY00370B (2016).

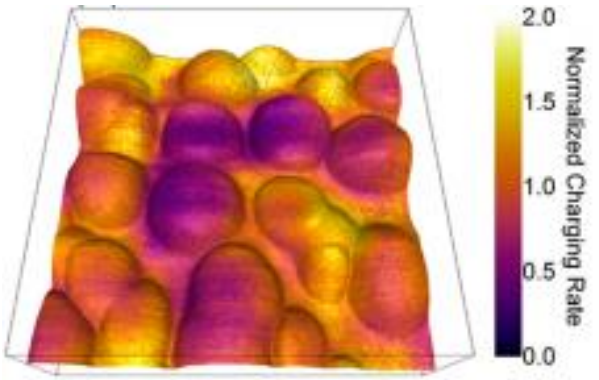
PHOTO-CARRIER DYNAMICS AT THE NANOSCALE

- Real characterization need.
- Assess morphology influence on the performance.

HOW TO MEASURE PHOTO-CARRIER DYNAMICS?

TRANSIENT (Pulsed excitation, decay time)	STEADY-STATE (Modulated excitation, averaged signal)
Photo Conductance (PCD, QSSPC)	
Short-Circuit Current (SCCD)/Open-Circuit Voltage (OCVD)	
Free Carrier Absorption	
Photoluminescence (PL)	
	Surface Photo Voltage (SPV)

D. K. Schroder, Semiconductor Material and Device Characterization, John Wiley & Sons, (2006)

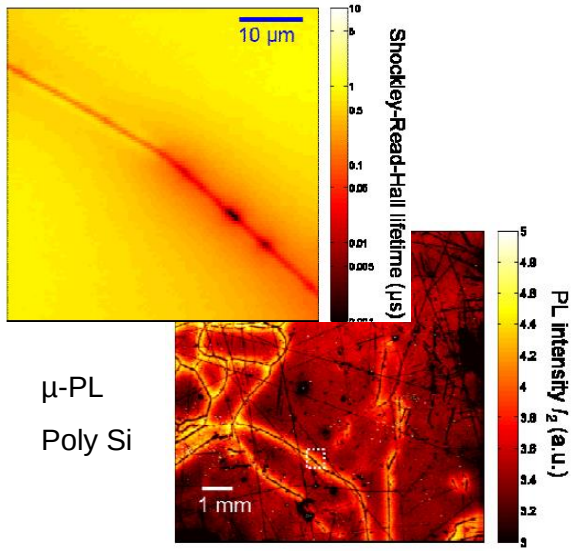


J. Phys. Chem. Lett. 2015, **6**, 2852−2858

SPECTROSCOPY AND/OR MAPPING AT 10 NM SCALE ?

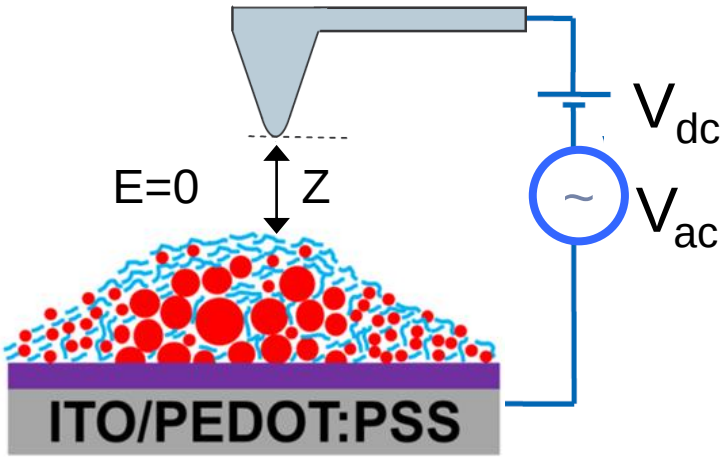
- **Kelvin Probe Force Microscopy**

  Organic, inorganic and hybrid photovoltaic materials



JAP ***108***, 033705 (2010)

KELVIN FORCE MICROSCOPY : PRINCIPLE



$$V_{CPD} = \frac{\Phi_{probe} - \Phi_{sample}}{|e|}$$

M. Nonnenmacher et al., Appl. Phys. Lett. 58, 25 (1991)
Ł. Borowik et al. Phys. Rev. B 82, 073302 (2010)

Feedback loop to cancel force /force gradient $V_{DC} = \pm V_{CPD}$

Force mode

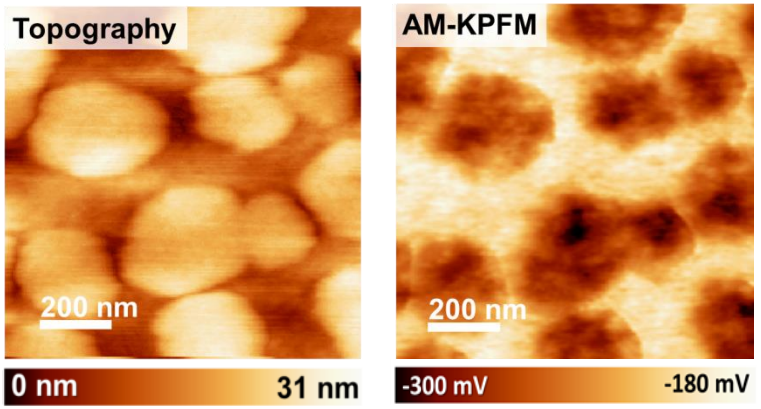
$$F_{\omega_{elec}} = \frac{\partial C}{\partial z}\sin(\omega t)\,(V_{DC} - V_{CPD})\,V_{AC}$$

Amplitude modulation (AM-KFM)

Force Gradient mode

$$\frac{\partial F_{\omega_{elec}}}{\partial z} = \frac{\partial^2 C}{\partial z^2}\,(V_{DC} - V_{CPD}) \times V_{AC}\sin(\omega t)$$

Frequency modulation (FM-KFM)

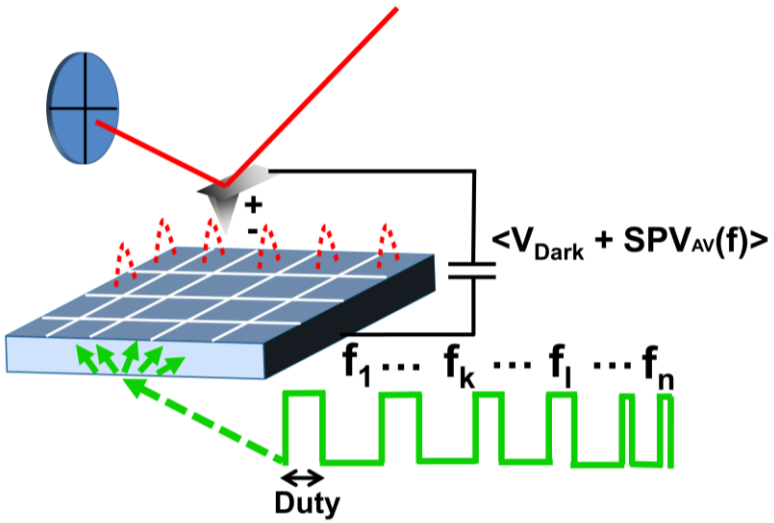


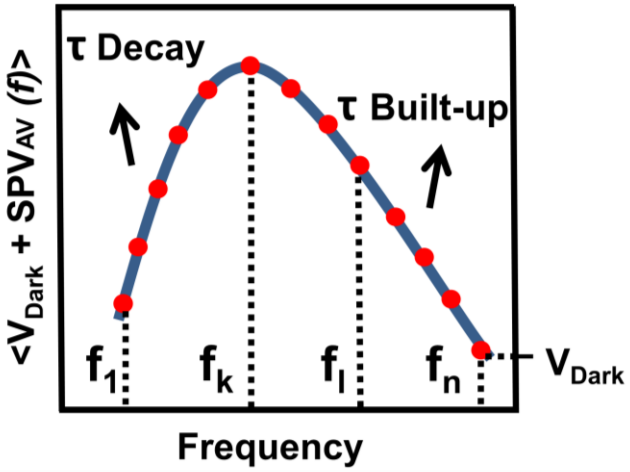
Resolution

Potential < 5 mV

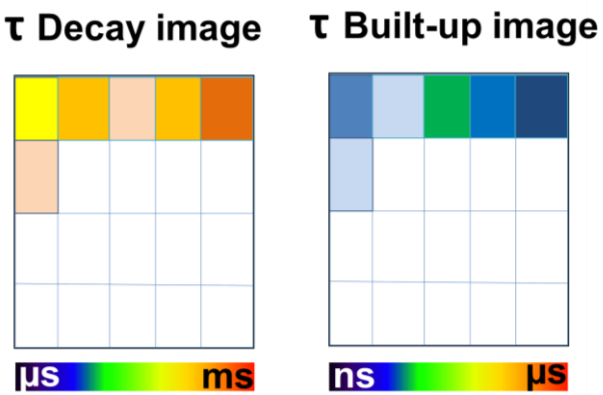
Spatial 5-50 nm

TECHNIQUE'S PRINCIPLE

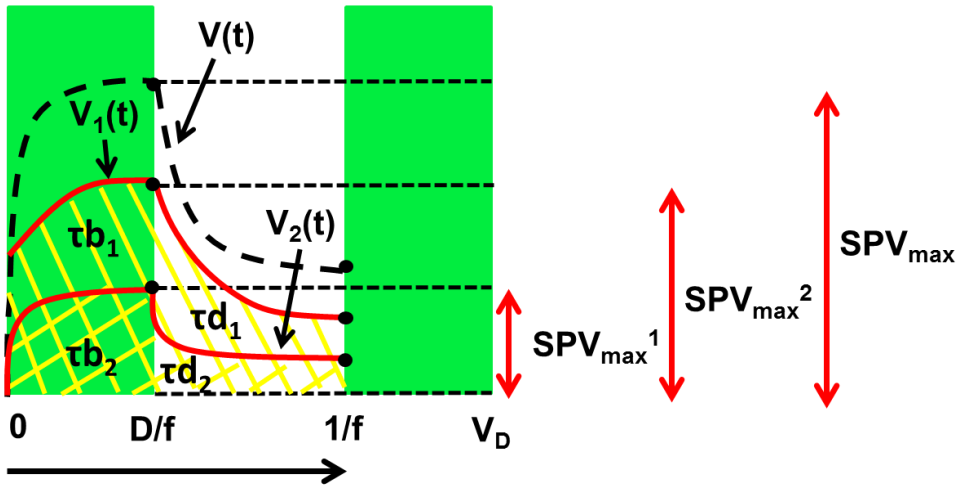


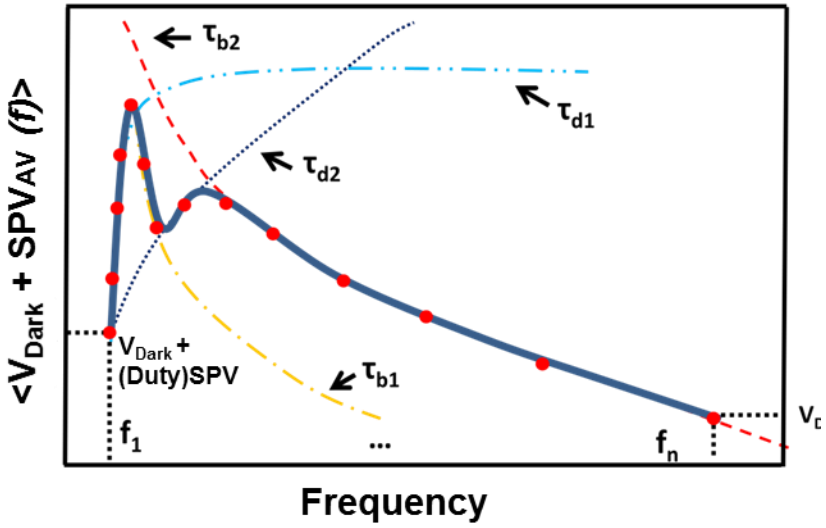


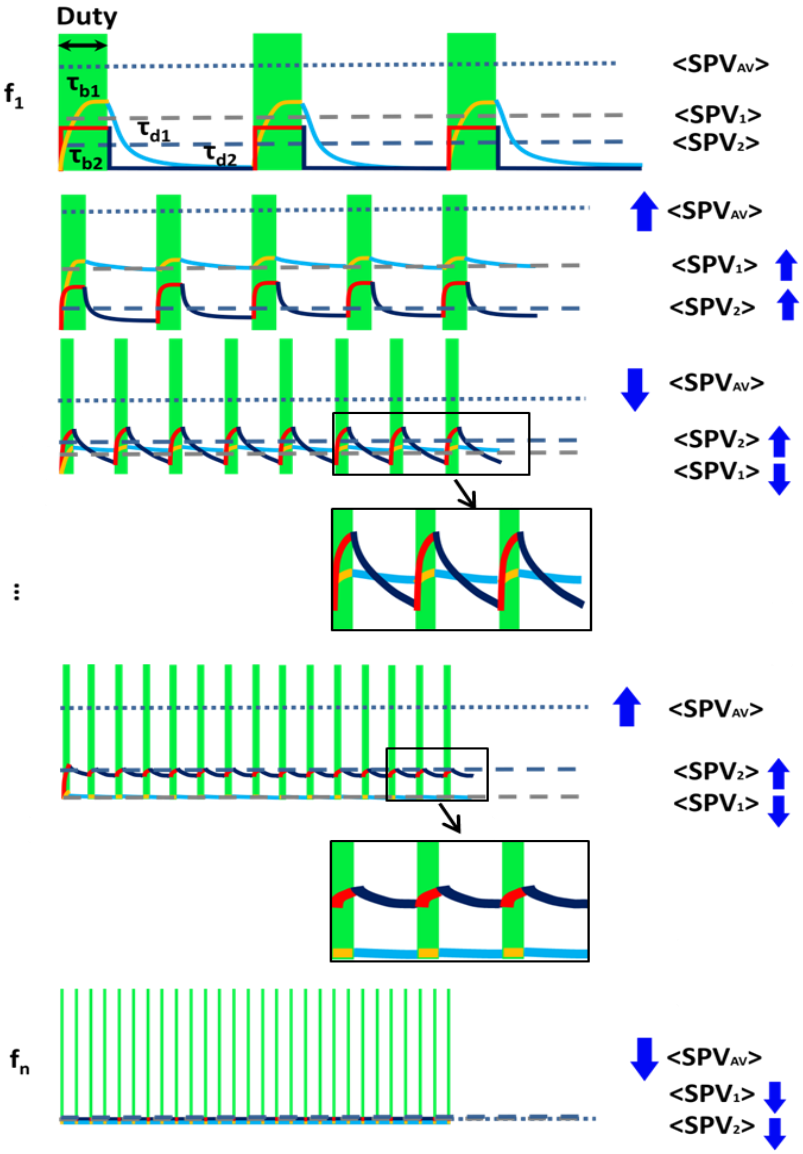
A curve fit is performed on each pixel to recalculate 2D images of the time-constants.



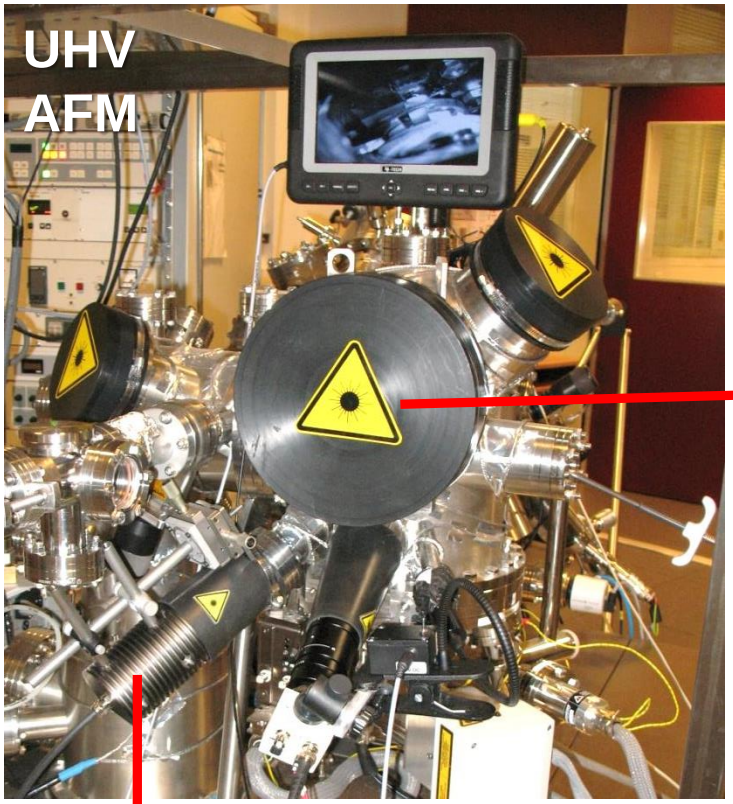
NATURE IS NOT THAT SIMPLE: ACCOUNTING FOR TWO SPV CONTRIBUTIONS



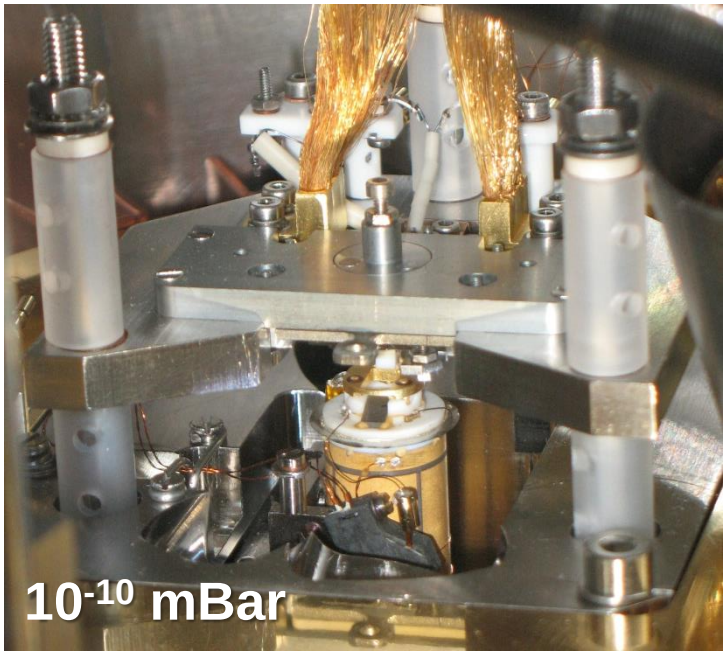




EXPERIMENTAL SETUP



Omicron UHV-AFM VT XA

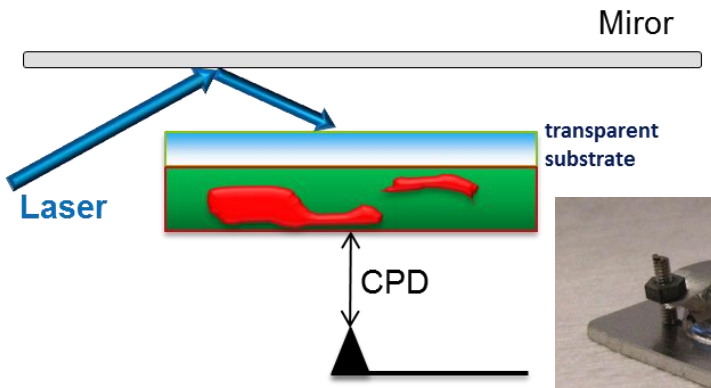


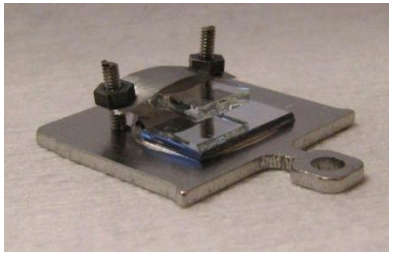
EXTERNAL ILLUMINATION

Red, green and blue lasers

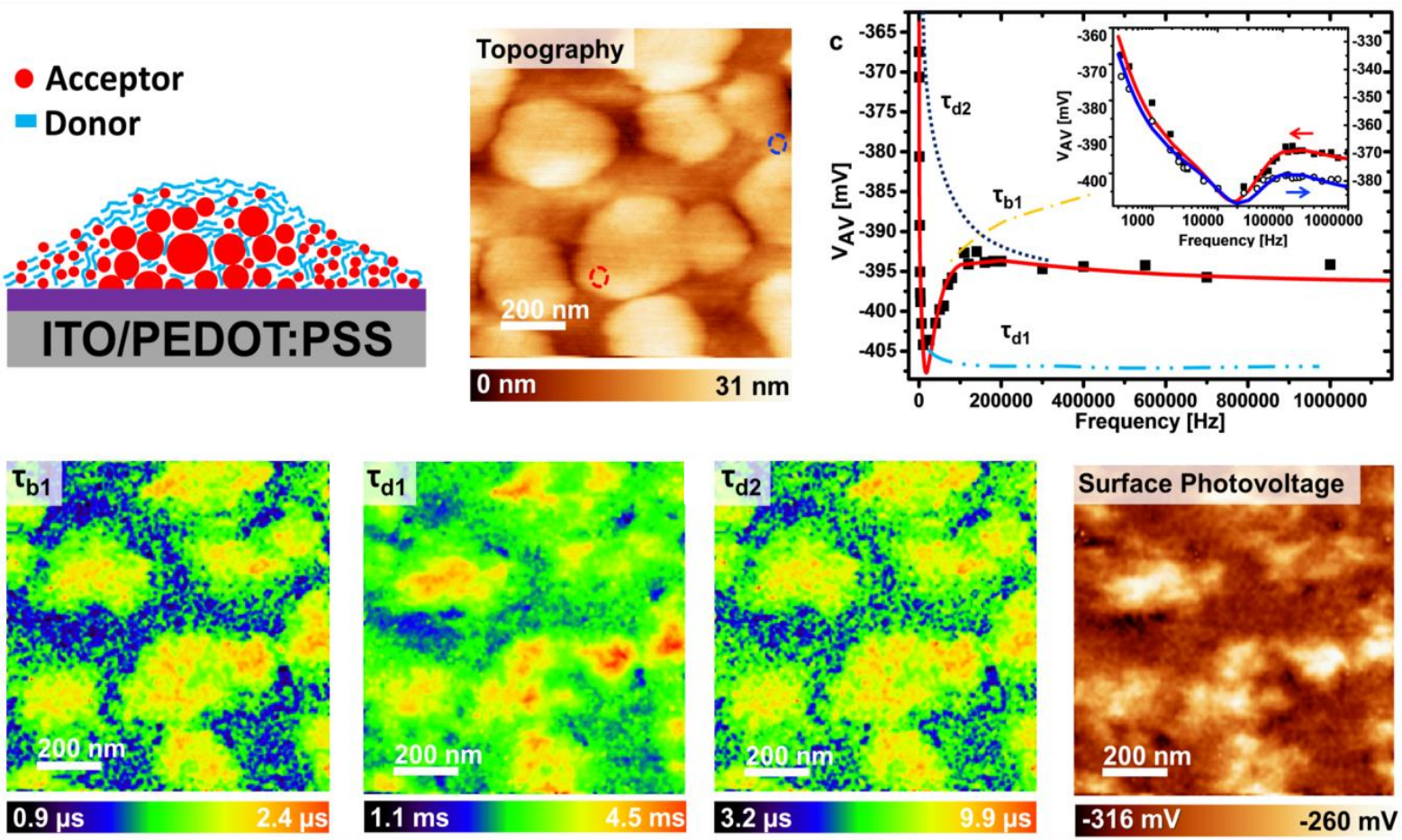
DC to 10 MHz

Power 0.2 to 80 mW



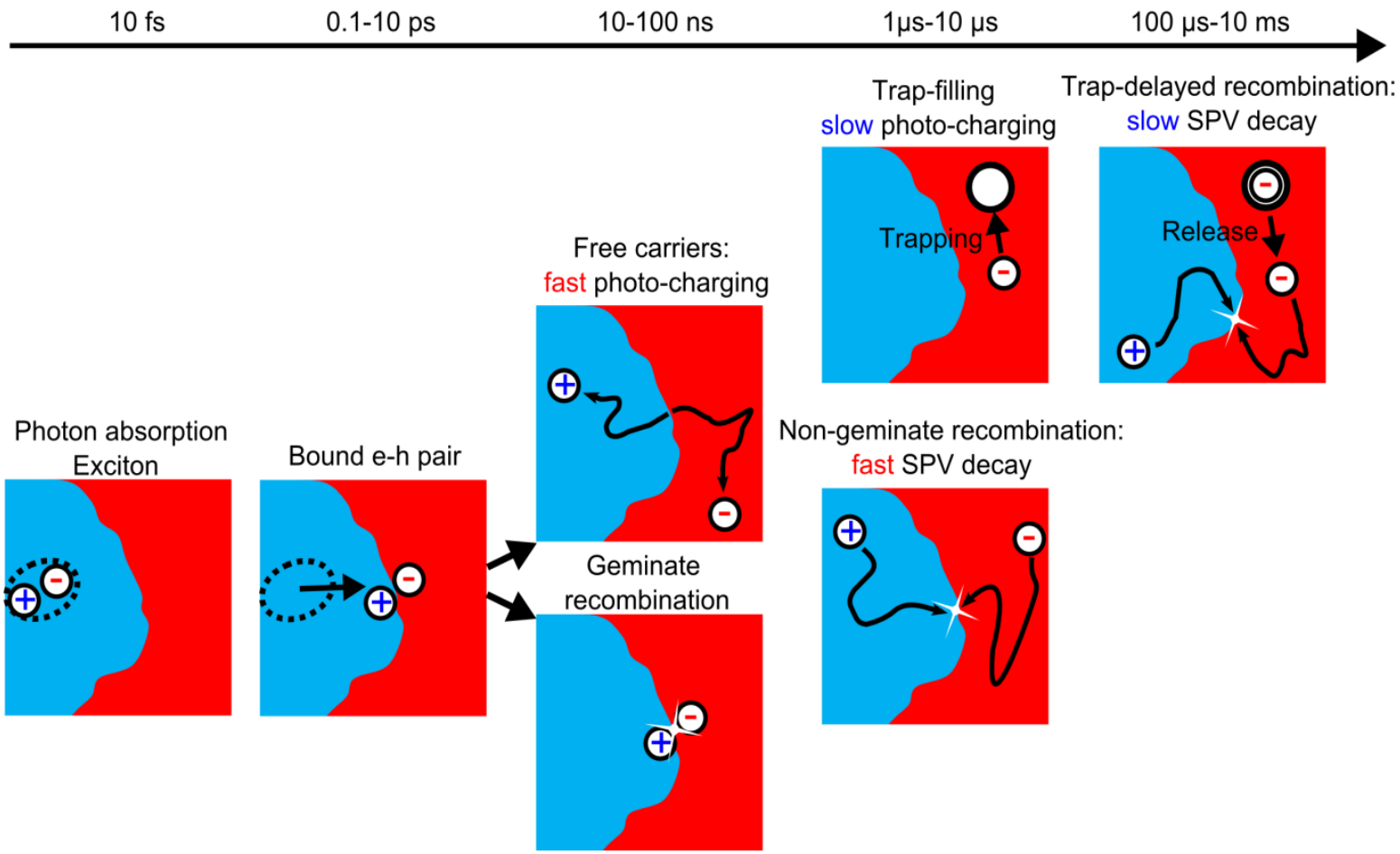


MULTI-DYNAMICAL IMAGING OF A LARGE-SCALE HETEROGENEOUS [71]PCBM:PDBS-TQX BLEND

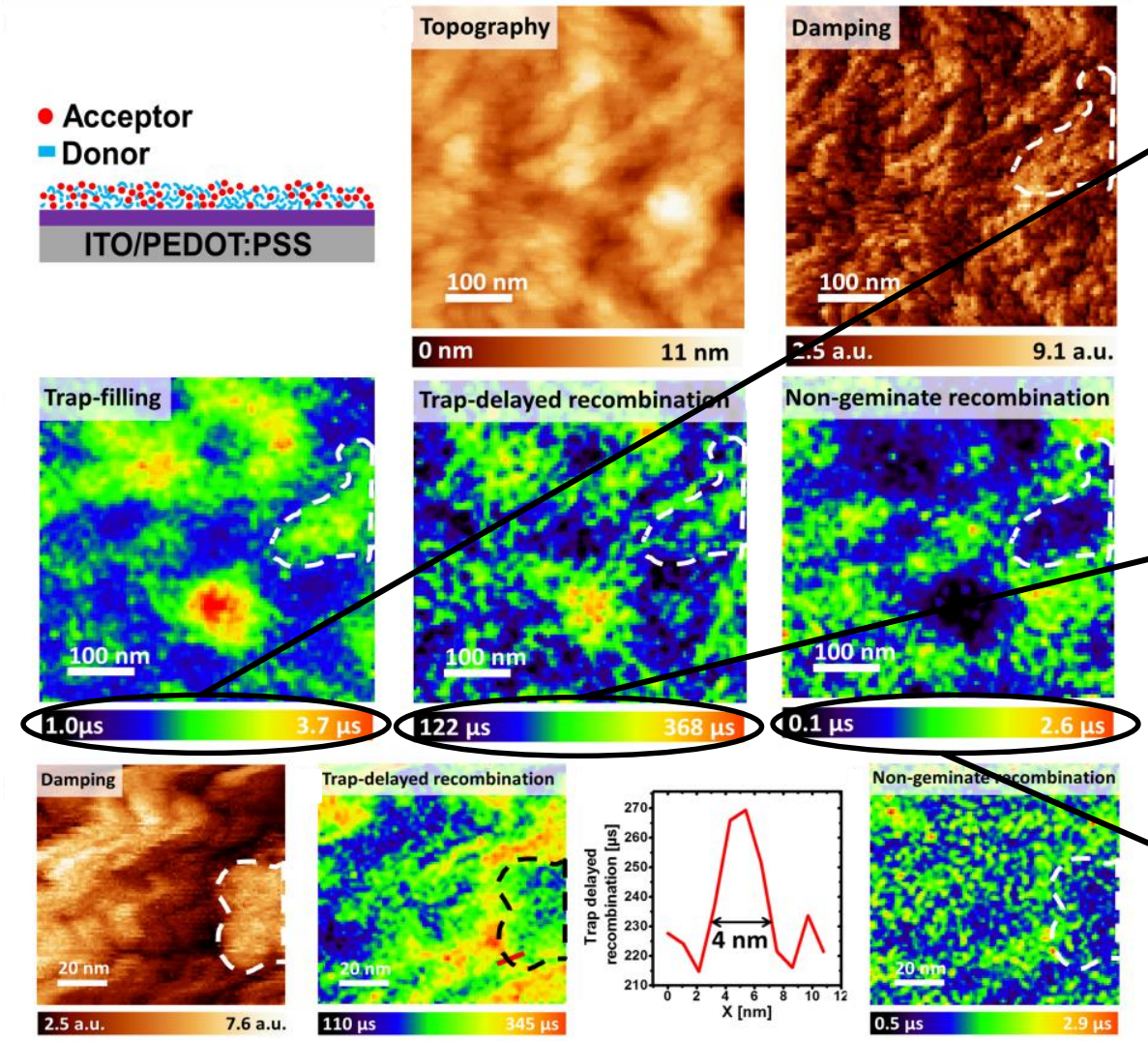


PHOTOCARRIERS DYNAMICS STRONGLY INFLUENCED BY SAMPLE'S MORPHOLOGY !

SURFACE PHOTO-VOLTAGE DYNAMICS IN BHJ ORGANIC PHOTOVOLTAICS



MULTI-DYNAMICAL IMAGING OF A NANO-PHASE SEGREGATED [70]PCBM:PDBS-TQX BLEND



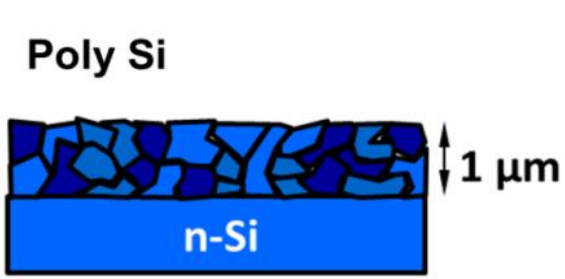
McNeill, C.; Hwang, I.; Greenham, N. Photocurrent Transients in All-Polymer Solar Cells: Trapping And Detrapping Effects. *J. Appl. Phys.* **2009**, 106, 024507.

Shuttle, C.; Treat, N.; Douglas, J.; Fréchet, J.; Chabinyc, M.
Deep Energetic Trap States in Organic Photovoltaic Devices.
Adv. Energy Mater. **2012**, 2, 111-119.

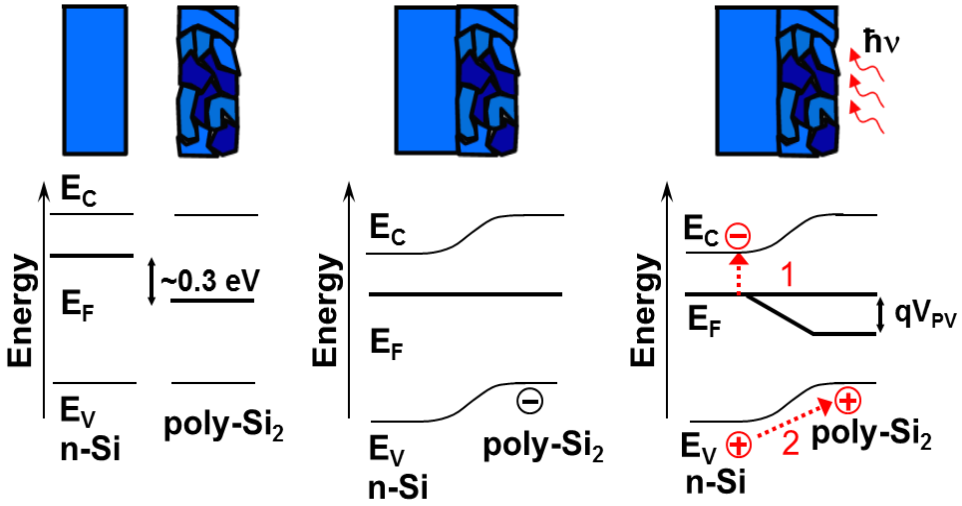
Elliott, L.; Basham, J.; Pernstich, K.; Shrestha, P.; Richter, L.; DeLongchamp, D.; Gundlach, D. Probing Charge Recombination Dynamics in Organic Photovoltaic Devices Under Open-Circuit Conditions. *Adv. Energy Mater.* **2014**, 4, 1400356.

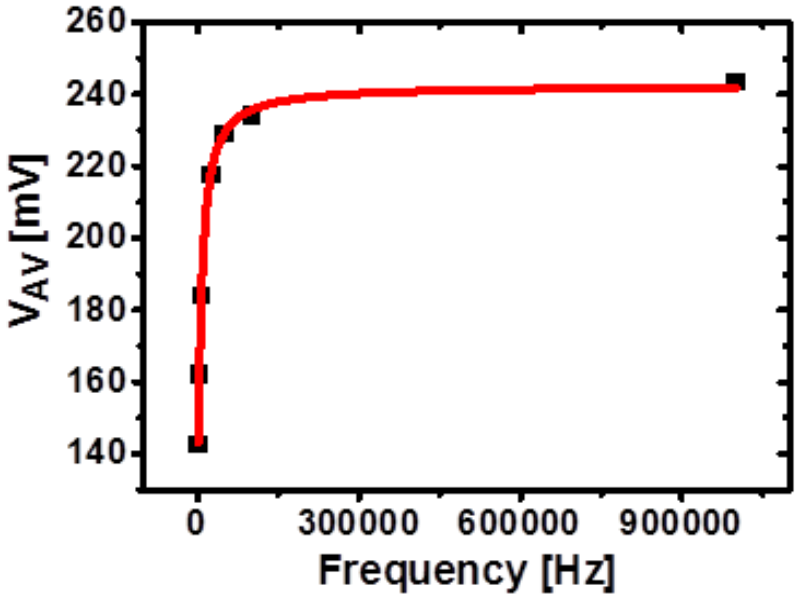
IMAGING THE MINORITY CARRIER LIFETIME VARIATIONS IN POLY-CRYSTALLINE SILICON

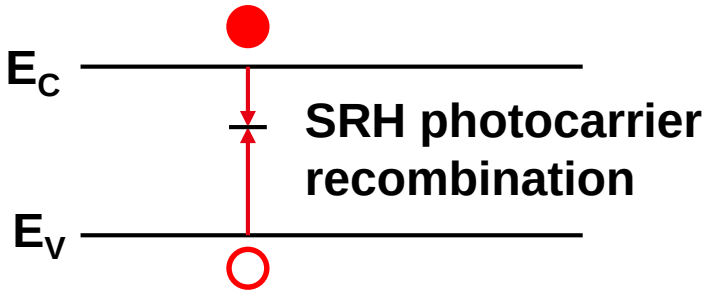
$$V_{av} = V_D + SPV_{max}\, D + SPV_{max}\, f\tau_d \left(1 - e^{\frac{-(1-D)}{f\tau d}}\right)$$



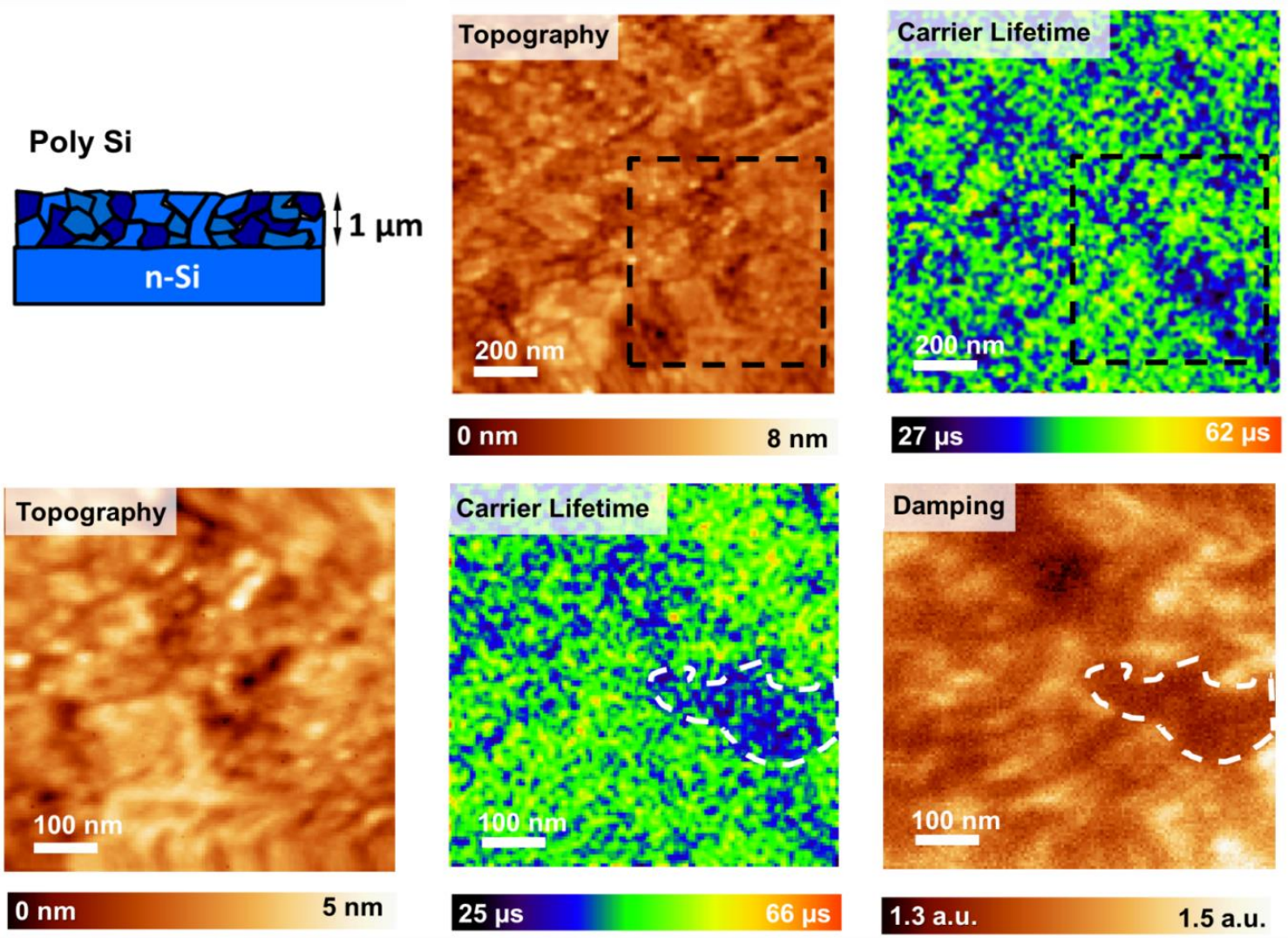
Doping level 10^{15} cm^{-3}





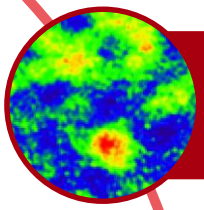


IMAGING THE MINORITY CARRIER LIFETIME VARIATIONS IN POLY-CRYSTALLINE SILICON

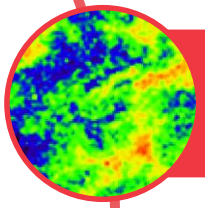


MEASUREMENTS ARE SENSITIVE TO SURFACE STATES !

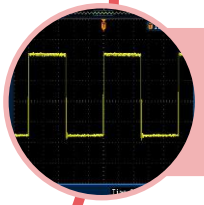
CONCLUSION



Time-resolved imaging of multi-dynamical photo-physical processes photovoltaic materials.



Nanometric lateral resolution.

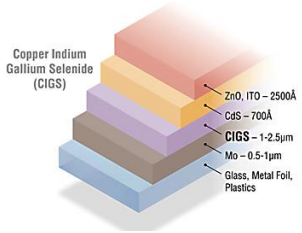


Temporal resolution only limited by the illumination and modulation setup.

Universal nano-characterization tool in the fields of photovoltaics and opto-electronics.

PERSPECTIVES

- Photo-carrier dynamics of several categories of D-A blends
- Investigation of Poly-Si after surface passivation
- Implementation in ambient conditions
- Comparative analysis with macroscopic measurements



FROM RESEARCH TO INDUSTRY

cea tech

Thank you for
your attention!

INSTITUT NANOSCIENCES
ET CRYOGÉNIE

leti