CEPID/CDMF
2013/07296-2

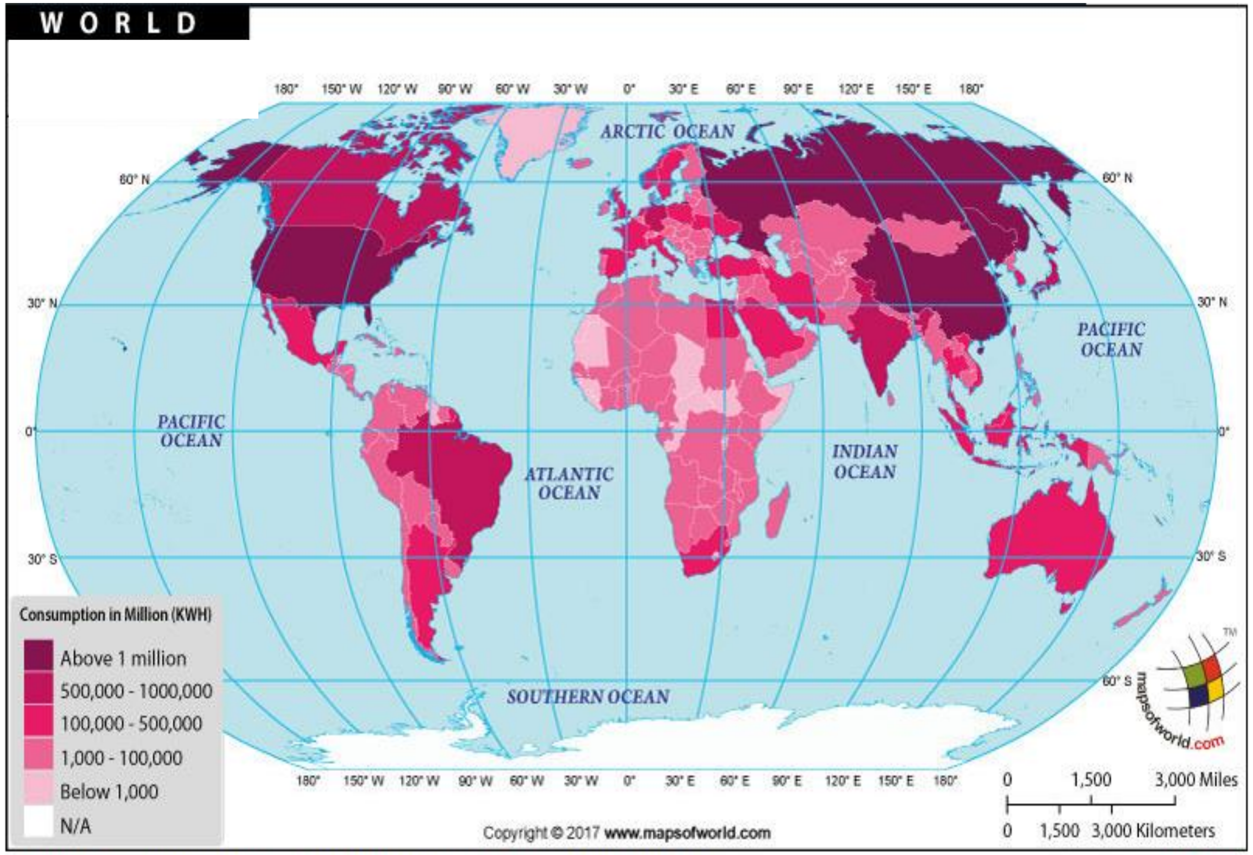
Exploring the Properties of Niobium Oxide Films for Electron Transport Layers in Perovskite Solar Cells

Carlos F. O. Graeff

UNESP

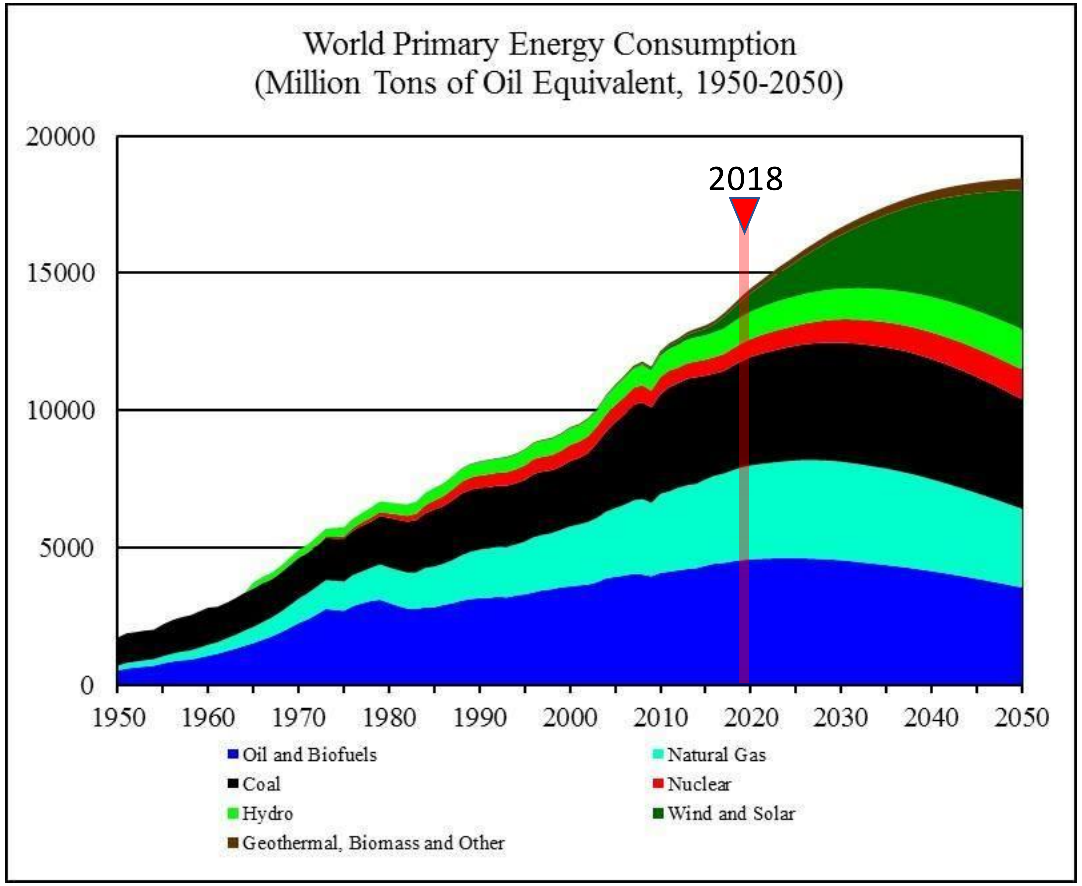
World Energy Consumption

The earth's population consumes ~ 21 trillion kWhrs of electricity, with ~ 2/3 generated using fossil fuels

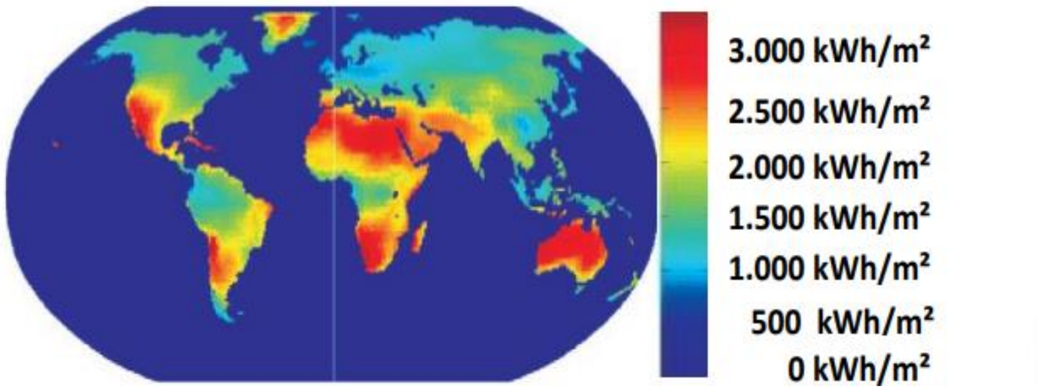


Description : This map shows the electricity consumption pattern around the world.

Disclaimer



Outlook on Global Solar Energy

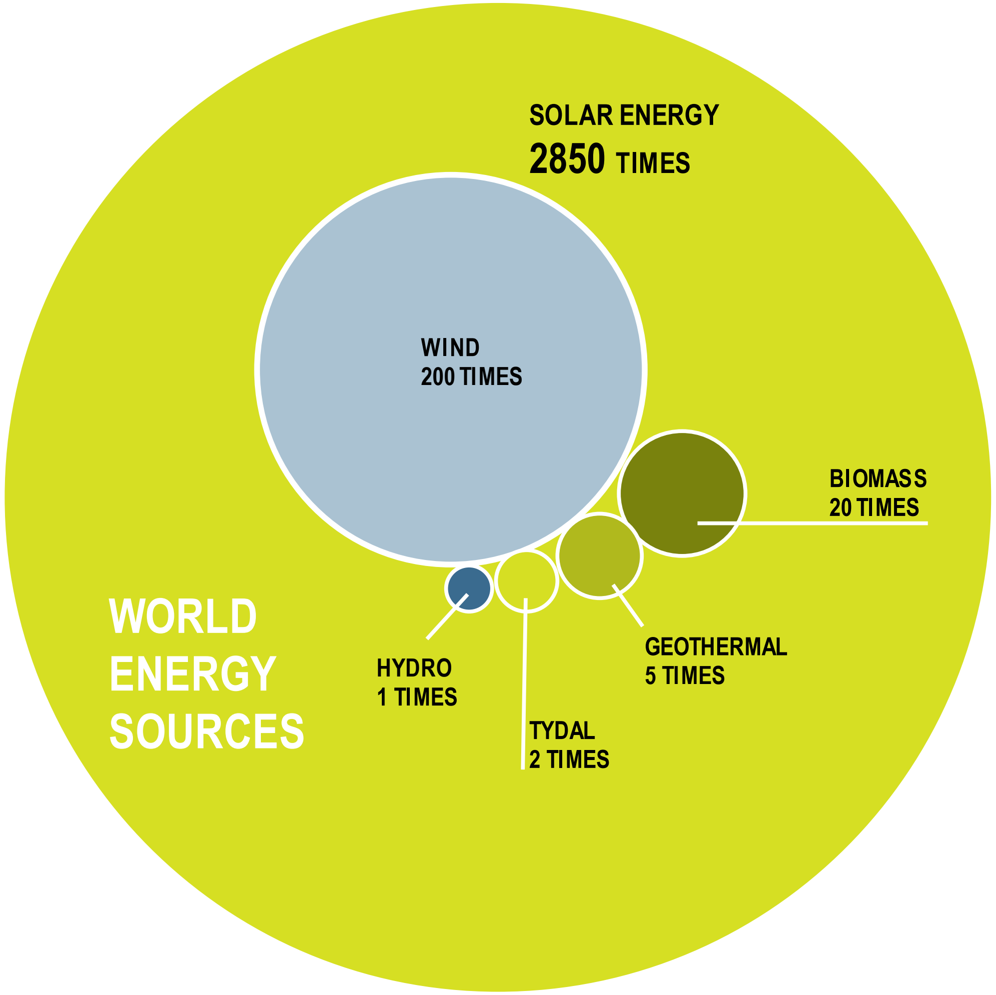


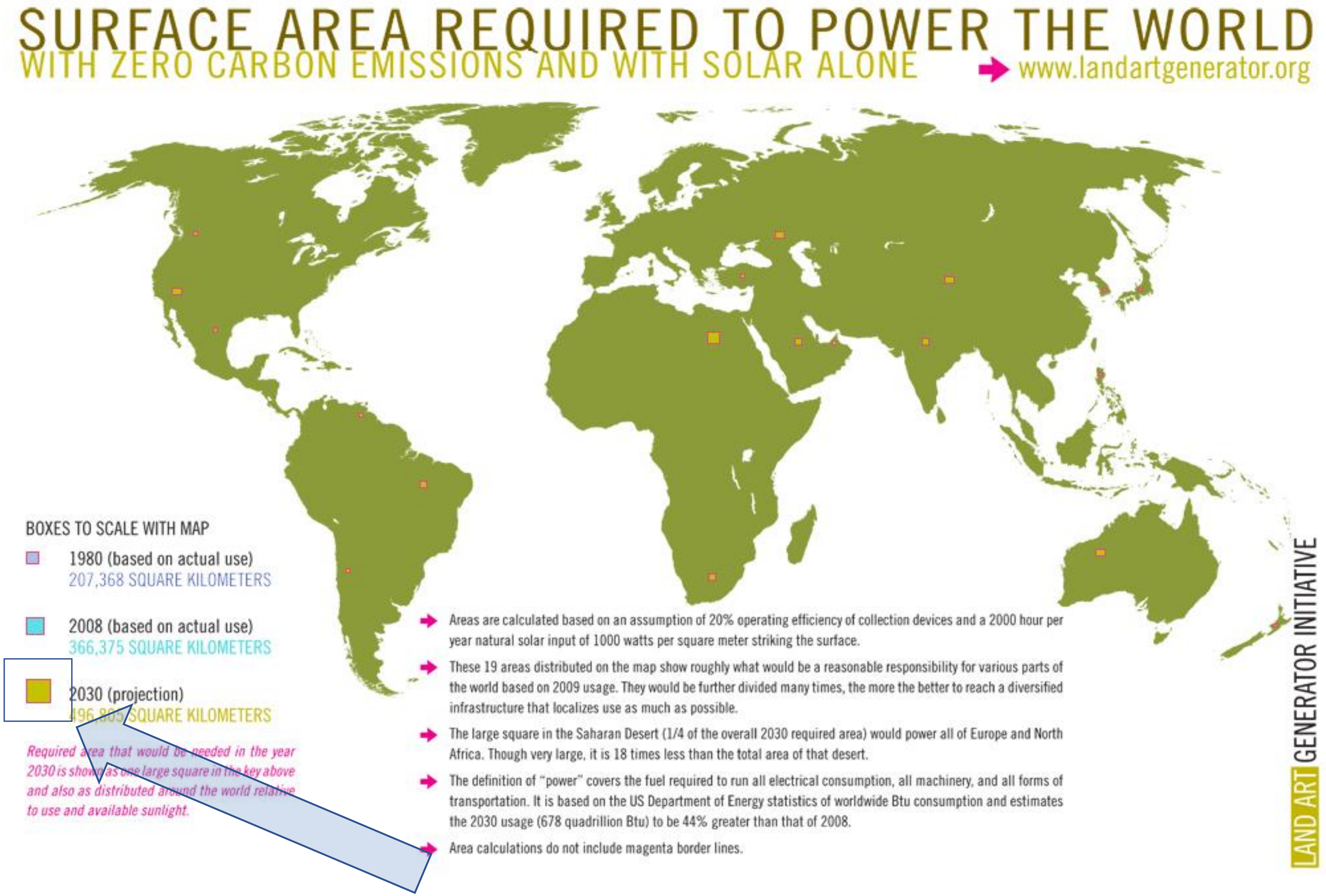
Global Solar generation for each country

nº	Country	1990	2000	2010	2014	2015	2016
1	China	0,5	2,0	2,1	12,0	15,0	19,9
2	United States	95,9	47,6	9,0	14,9	15,4	17,1
3	Japan	0,3	26,0	9,8	12,0	14,3	14,9
4	Germany	0,3	5,5	35,2	18,4	15,1	11,5
5	Italy	1,0	1,7	5,7	11,4	9,0	6,9
6	Spain	1,5	1,6	21,3	7,0	5,4	4,1
7	India	-	0,6	0,8	2,2	2,6	3,6
8	United Kingdom	-	0,1	0,1	2,1	3,0	3,1
9	France	-	0,5	1,9	3,0	2,9	2,5
10	Australia	-	4,3	2,9	2,5	2,3	2,1
11	South Chorea	-	0,5	2,3	1,3	1,6	1,6
12	Greece	-	-	0,5	1,9	1,5	1,2
13	South Africa	-	-	0,1	0,6	1,1	1,0
14	Canada	-	1,5	0,7	1,0	1,0	0,9
15	Belgium	-	-	1,7	1,5	1,2	0,9
	Other	0,5	8,2	5,9	8,4	8,7	8,9
	World	**100,0**	**100,0**	**100,0**	**100,0**	**100,0**	**100,0**
	World (TWh)	**0,4**	**1,1**	**33,3**	**196,3**	**256,2**	**333,1**
	%/total*	**0,003**	**0,007**	**0,15**	**0,8**	**1,1**	**1,4**

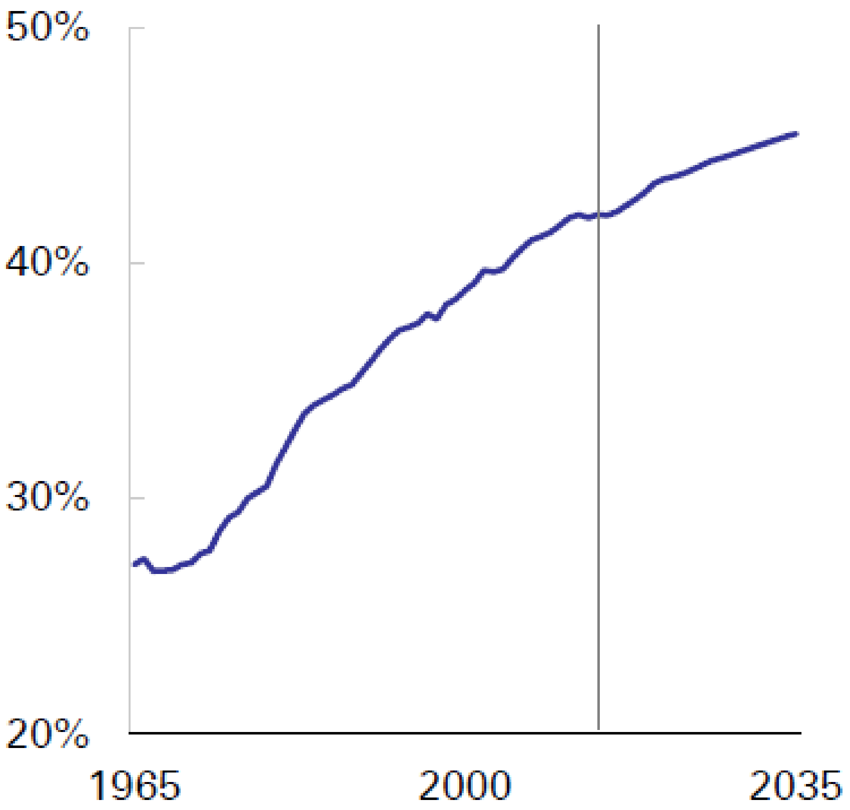
***% calculated considering the global electrical energy production**

All renewable energy sources provide 3078x the global energy demand




SURFACE AREA REQUIRED TO POWER THE WORLD
WITH ZERO CARBON EMISSIONS AND WITH SOLAR ALONE
www.landartgenerator.org
BOXES TO SCALE WITH MAP
1980 (based on actual use)
207,368 SQUARE KILOMETERS
2008 (based on actual use)
366,375 SQUARE KILOMETERS
2030 (projection)
496,805 SQUARE KILOMETERS
Required area that would be needed in the year 2030 is shown as one large square in the key above and also as distributed around the world relative to use and available sunlight.
Areas are calculated based on an assumption of 20% operating efficiency of collection devices and a 2000 hour per year natural solar input of 1000 watts per square meter striking the surface.
These 19 areas distributed on the map show roughly what would be a reasonable responsibility for various parts of the world based on 2009 usage. They would be further divided many times, the more the better to reach a diversified infrastructure that localizes use as much as possible.
The large square in the Saharan Desert (1/4 of the overall 2030 required area) would power all of Europe and North Africa. Though very large, it is 18 times less than the total area of that desert.
The definition of "power" covers the fuel required to run all electrical consumption, all machinery, and all forms of transportation. It is based on the US Department of Energy statistics of worldwide Btu consumption and estimates the 2030 usage (678 quadrillion Btu) to be 44% greater than that of 2008.
Area calculations do not include magenta border lines.
LAND ART GENERATOR INITIATIVE

A fração da energia primaria mundial usada reservada à produção de eletricidade cresce.



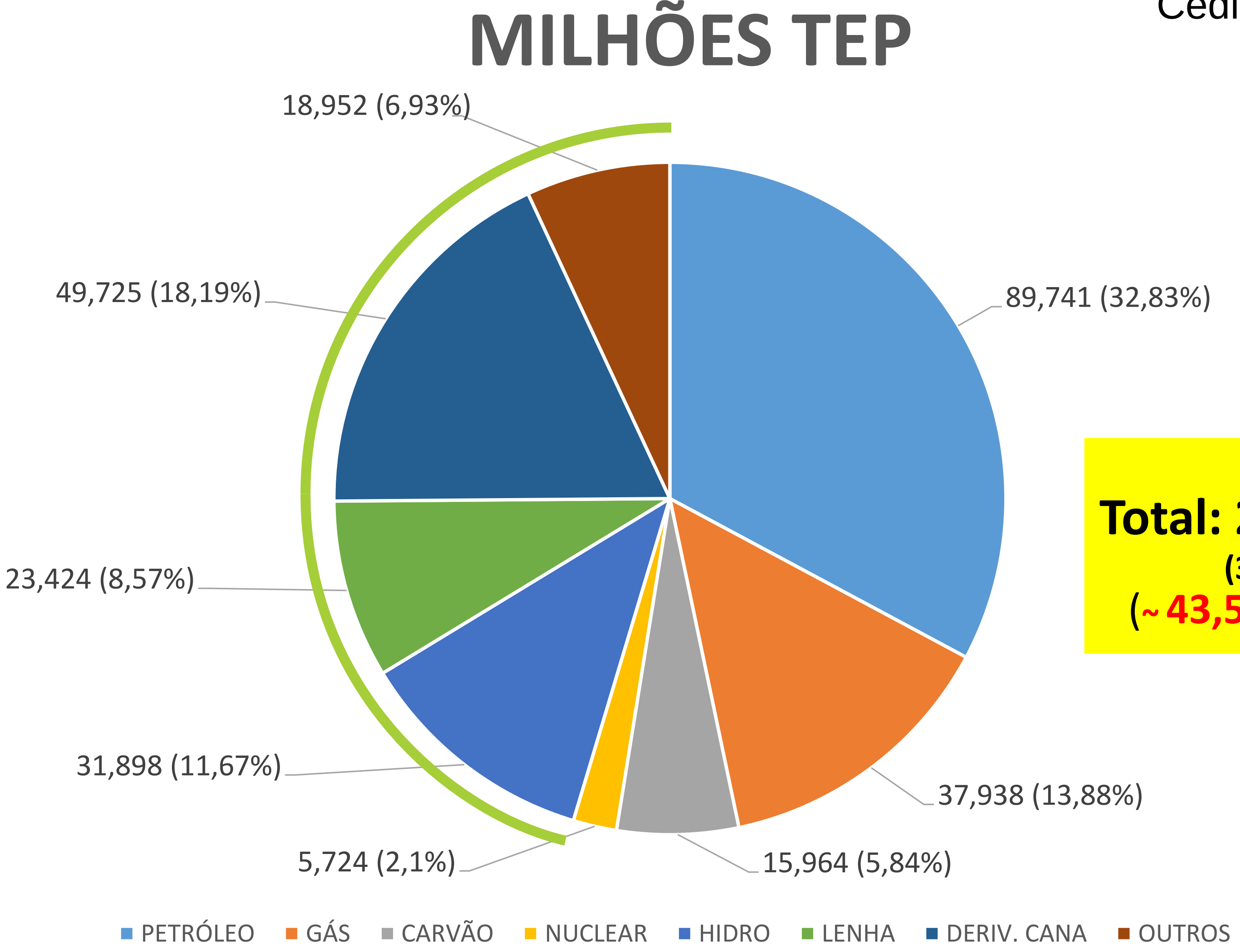
Em 1965 perto de 27% da energia primária do mundo eram usados para produzir eletricidade.

Em 2035 quase metade da energia primária mundial deverá ser usada apenas para produzir eletricidade.

Energy Outlook 2016 - BP

In Brazil

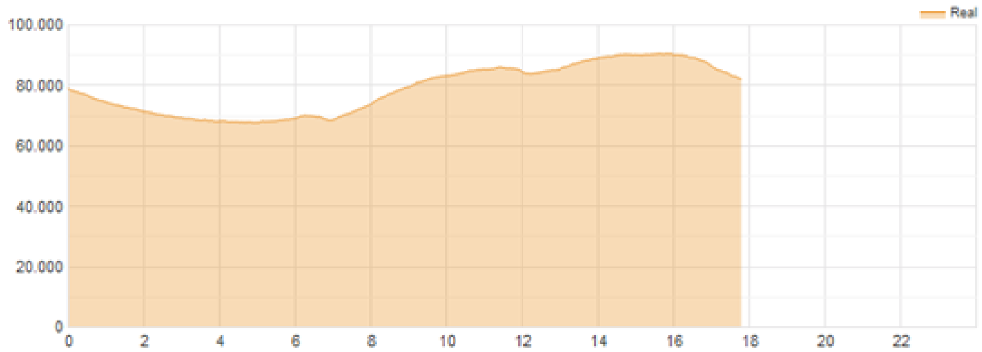
Cedido por Antonio Camargo



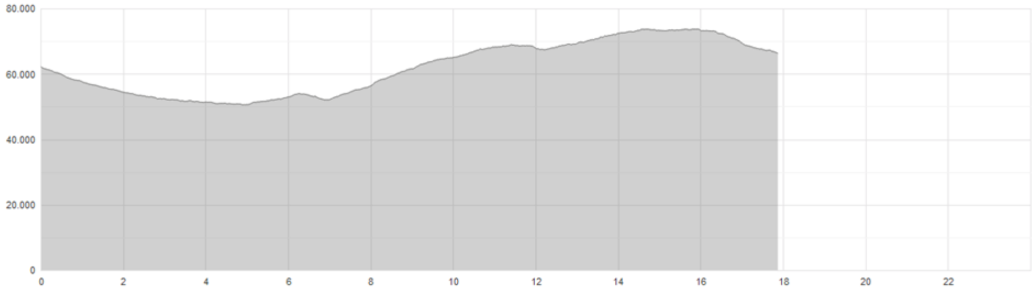
Total: 273,37 MTOE
(3.180 TWh)
(~ 43,5% renováveis)

Cedido por Antonio Camargo

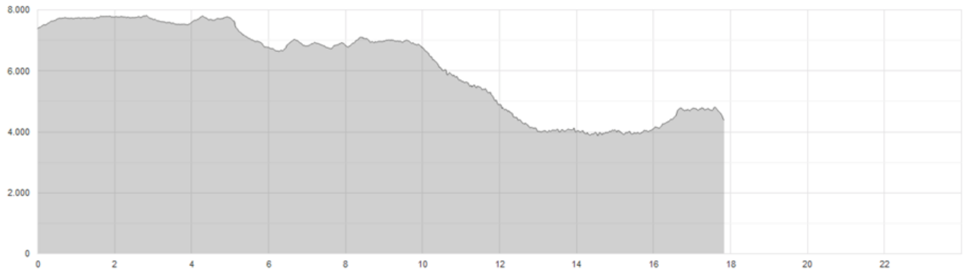
Continuação - 30/01/2019 às 17:47



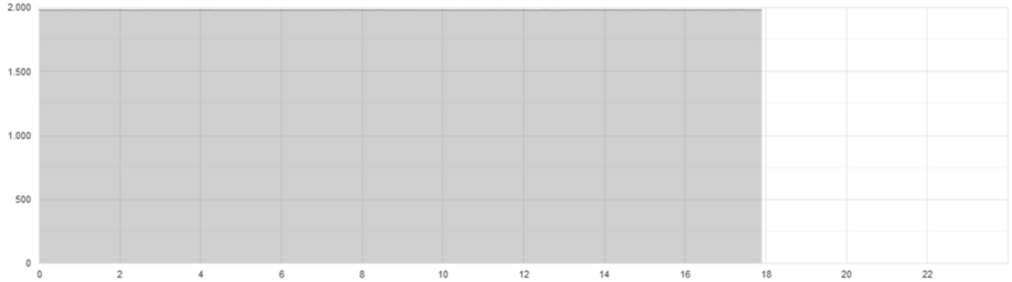
SIN



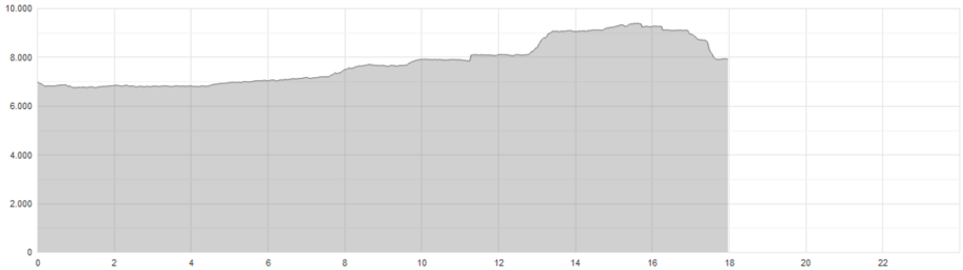
HIDRO



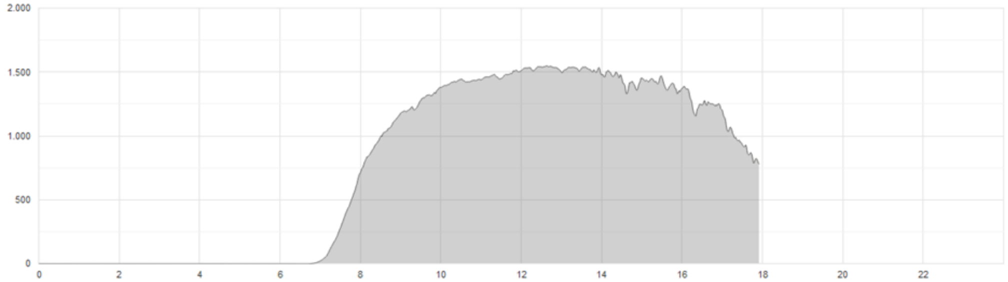
EÓLICA



NUCLEAR



TÉRMICA

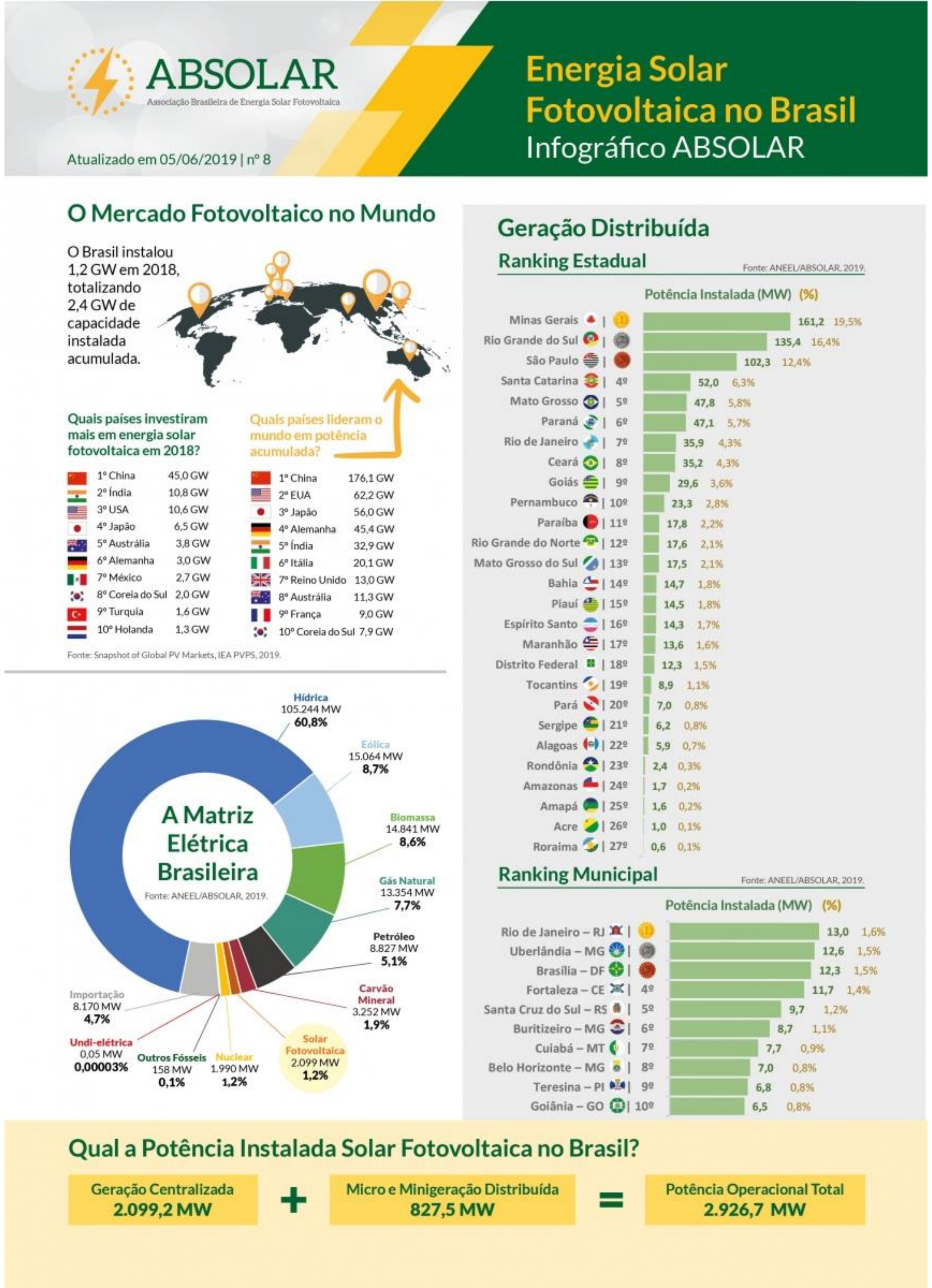


SOLAR

In Brazil

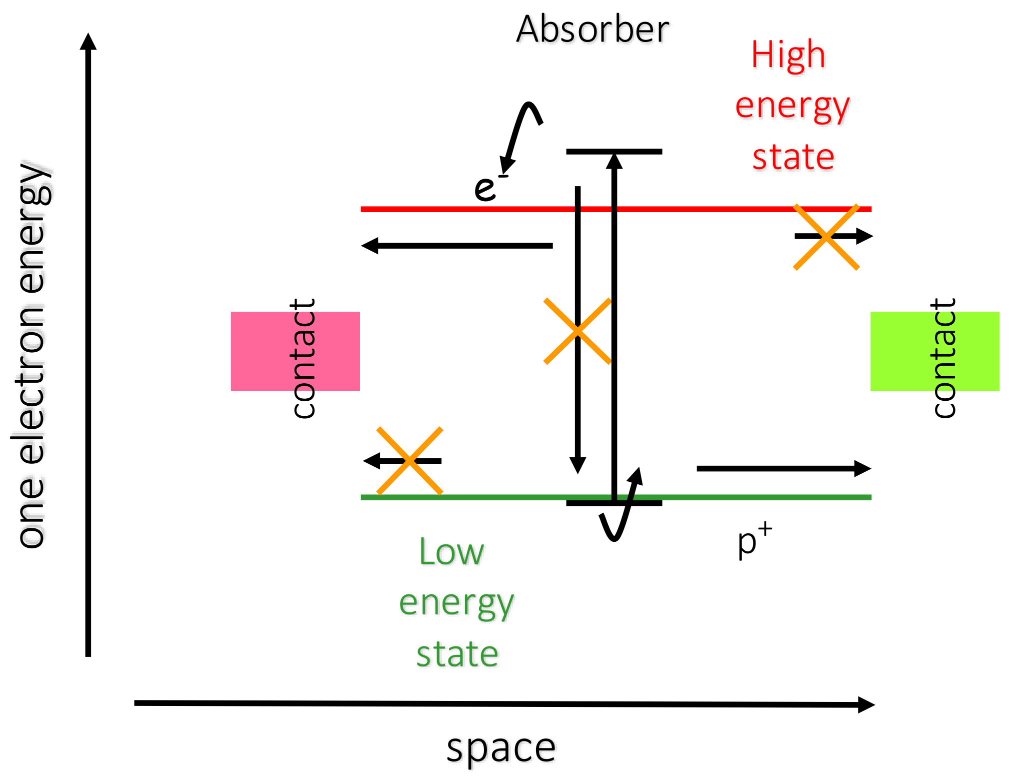
Main Industries

Photovoltaics > Nuclear



The Photovoltaic (PV) Effect

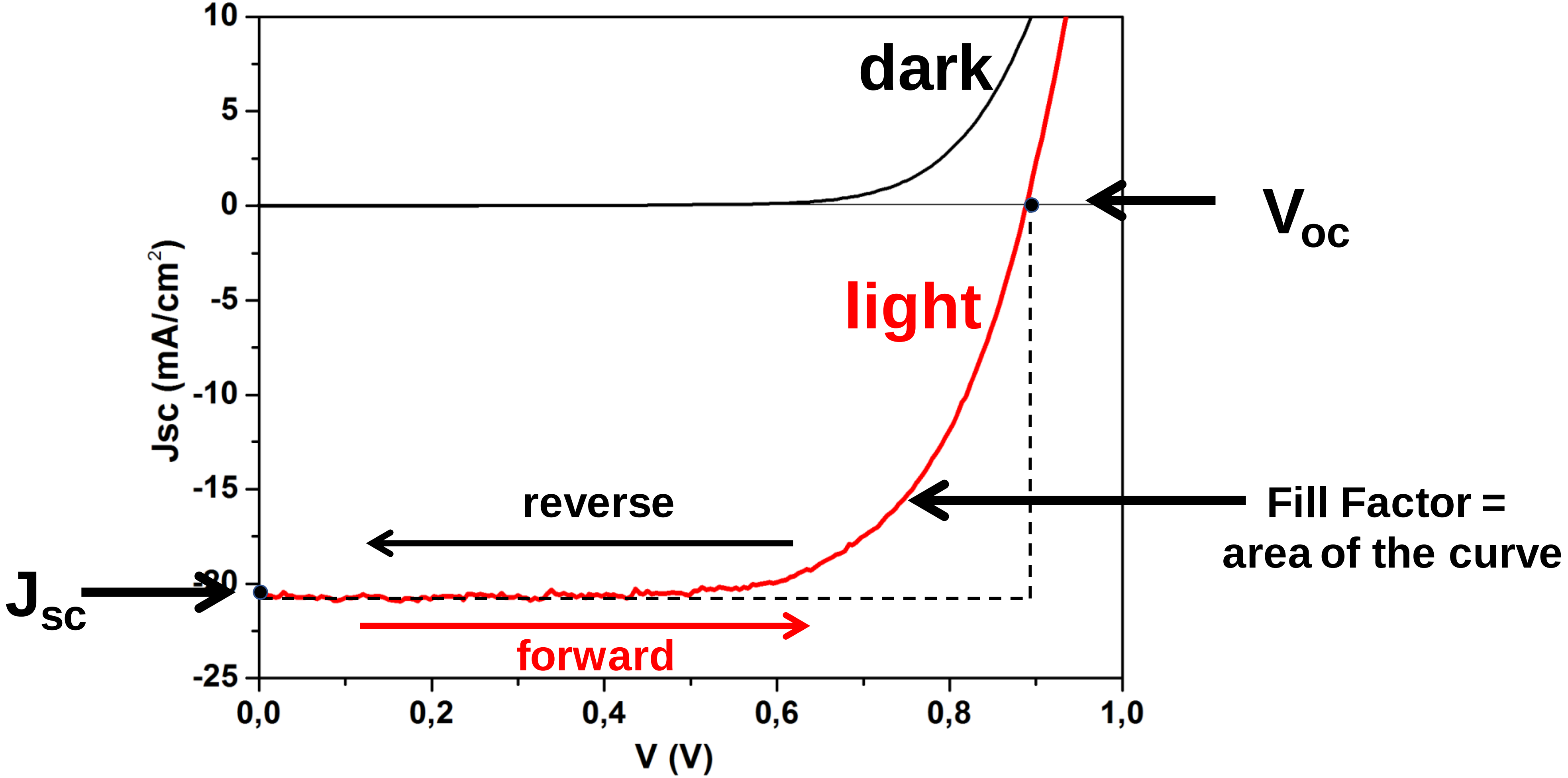
Generalized picture



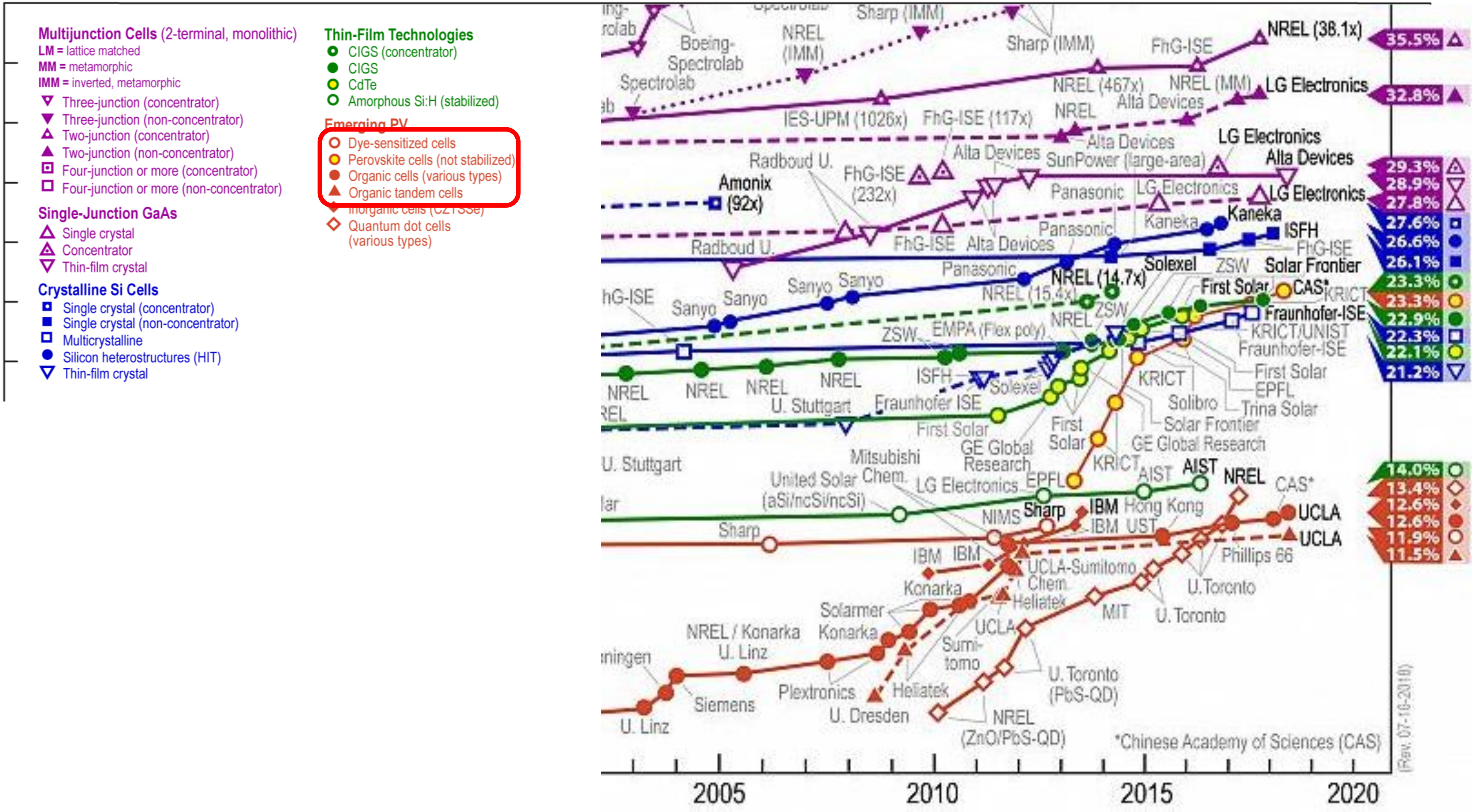
- **Metastable high and low energy states**
- **Absorber** transfers charges into high and low energy state
- **Driving force** brings charges to contacts
- **Selective** contacts

Green, M.A., Photovoltaic principles. Physica E, 14 (2002) 11-17

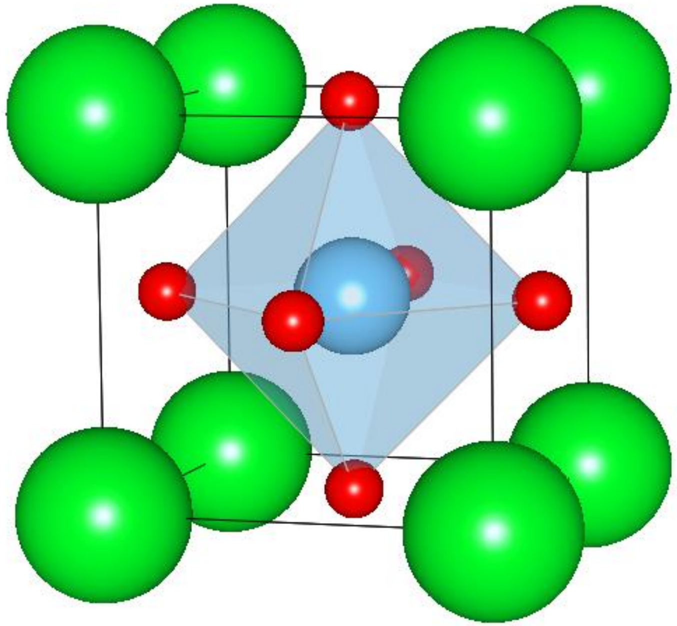
Measuring a solar cell



Best Research-Cell Efficiencies



Perovskite material



A^{+} cations

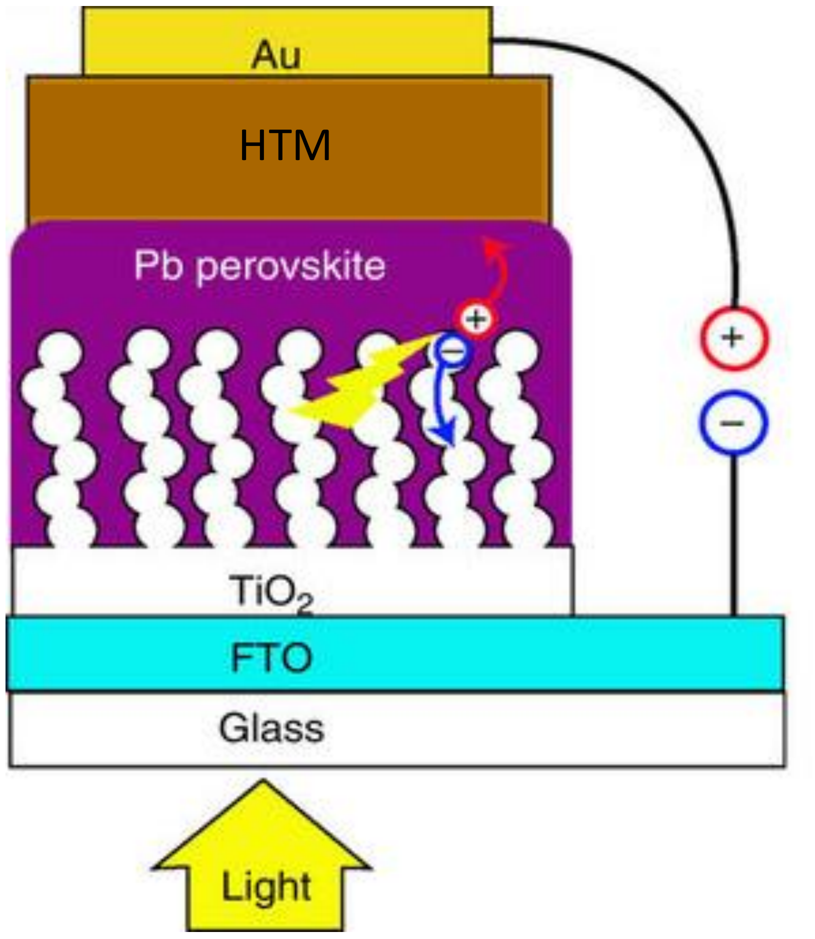
methylammonium (MA^{+}); formamidinium (FA^{+}); cesium (Cs^{+}), rubidium (Rb^{+}); ethylammonium (EA^{+}); guanidinium (GA^{+})

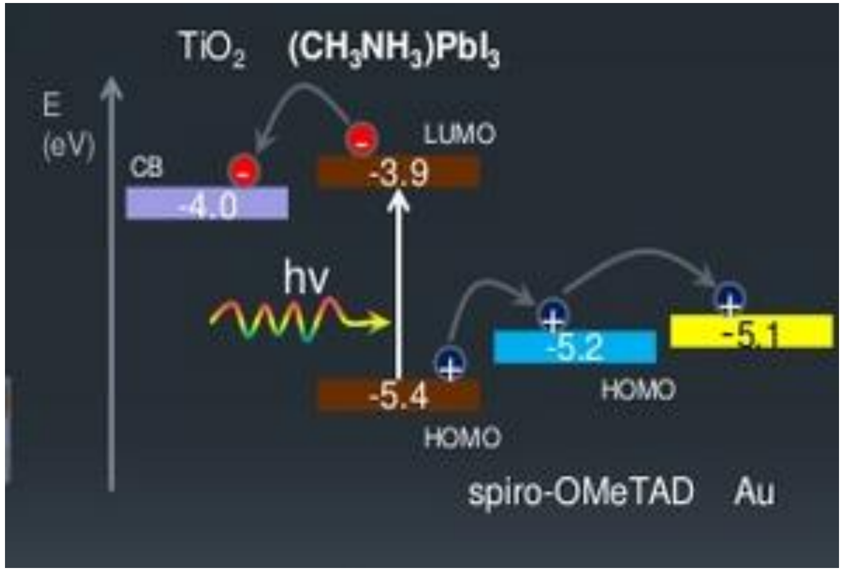
X^{-} anions (I^{-}; Br^{-}, Cl^{-})

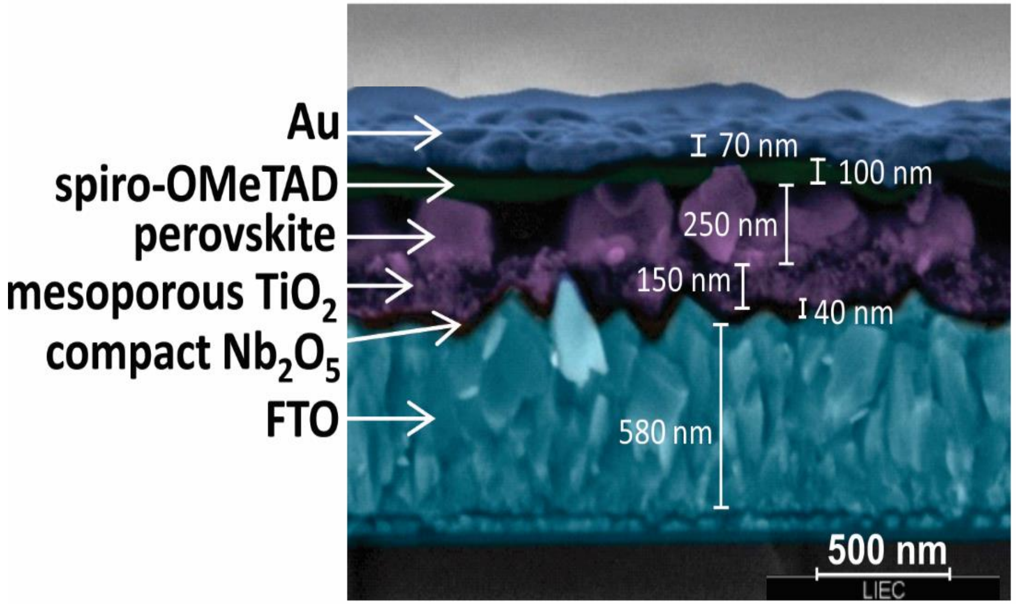
B^{2+} cations (Pb^{+2}; Sn^{+2}; Ge^{+2})

Most used material : $CH_3NH_3PbI_3$

Work Principle of perovskite solar cells





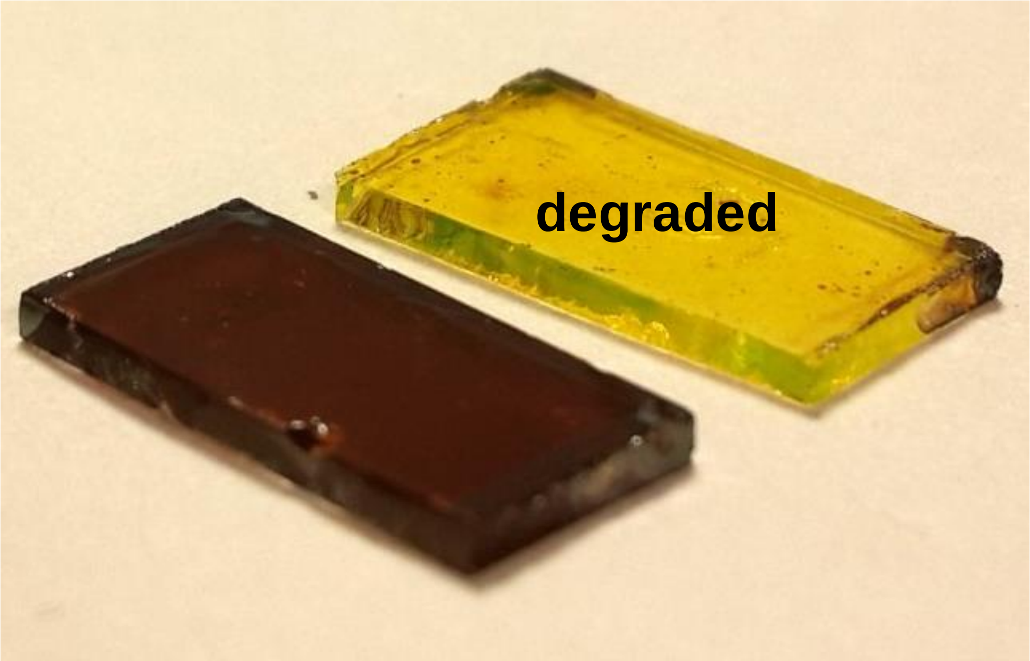


Nature Communications **5**, Article number: 3834 doi:10.1038/ncomms4834

Challenges in perovskite solar cells

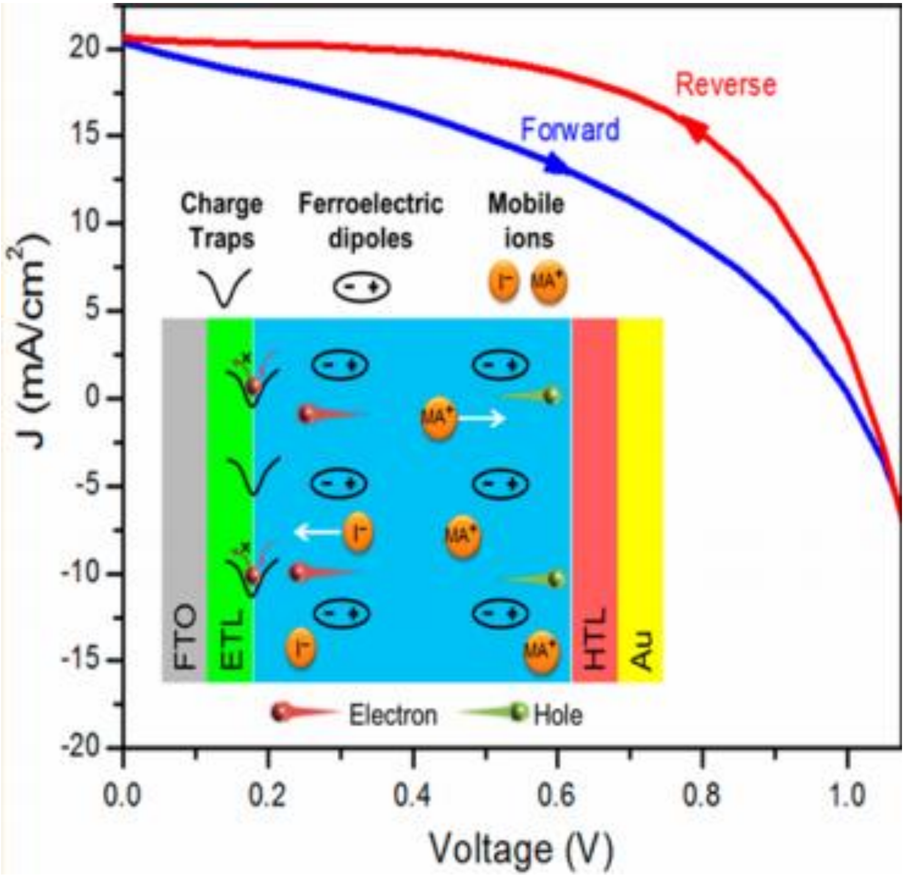
Degradation

- Intrinsic defect of perovskite material
  (volatile organic cations, ions diffusion)
- Interfaces,
- Stable conductive hole material,
- Encapsulation



Hysteresis

- Charge traps- charge accumulation
- Mobile ions (I^-, Cl^-, methylamonium$^+$)
- Ferroeletric dipoles



Our contribution

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/matlet

ELSEVIER

Nb_2O_5 hole blocking layer for hysteresis-free perovskite solar cells

Silvia L. Fernandes [a,d,*], Anna C. Véron [b], Nilton F.A. Neto [c,d], Frank A. Nüesch [b], José H. Dias da Silva [c], Maria A. Zaghete [a], Carlos F. de O. Graeff [c]

frontiers in Chemistry

ORIGINAL RESEARCH
published: 06 February 2019
doi: 10.3389/fchem.2019.00050

Check for updates

Exploring the Properties of Niobium Oxide Films for Electron Transport Layers in Perovskite Solar Cells

Silvia Leticia Fernandes [1], Luiz Gustavo Simão Albano [2], Lucas Jorge Affonço [2], José Humberto Dias da Silva [2], Elson Longo [1] and Carlos Frederico de Oliveira Graeff [2]*

[1] Department of Chemistry, Federal University of São Carlos (UFSCAR), São Carlos, Brazil, [2] Department of Physics, School of Sciences, São Paulo State University (UNESP), Bauru, Brazil

Luz mais eficiente

Células solares de perovskita podem ser uma alternativa mais barata e eficaz aos módulos de silício que dominam o mercado mundial de painéis fotovoltaicos

YURI VASCONCELOS | ED. 260 | OUTUBRO 2017

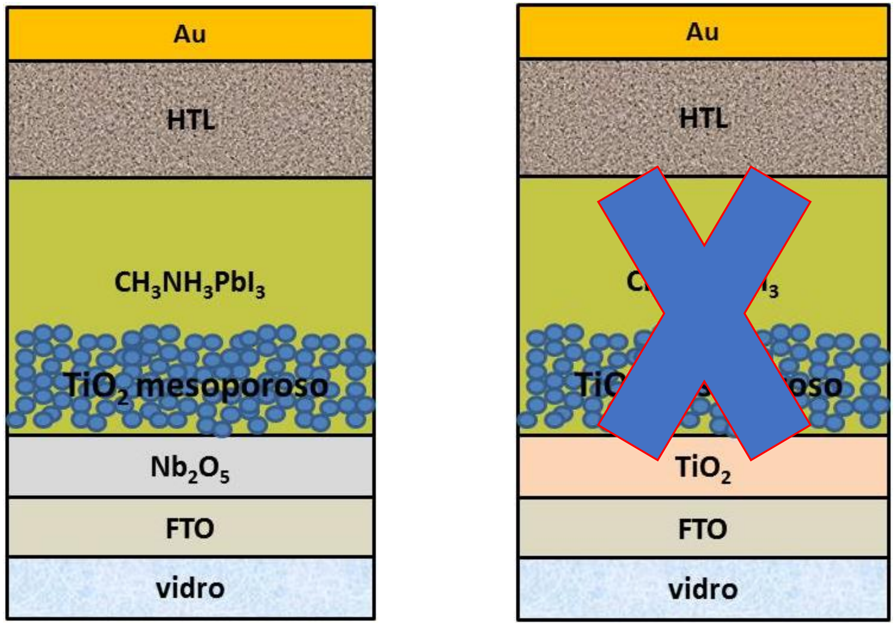
FAPESP bulletin

Uma nova geração de células solares feitas a partir de um material sintético cristalino conhecido como perovskita foi escolhida como uma das 10 tecnologias emergentes de 2016 pelo Fórum Econômico Mundial, organização suíça que reúne anualmente líderes empresariais e políticos para discutir questões globais. O material tem provocado entusiasmo entre cientistas por causa de sua elevada capacidade de

Nb_2O_5 vs TiO_2

Nb_2O_5 is similar to TiO_2, with

- better **chemical stability**
- **higher electronegativity** than TiO_2
- band gap allows higher V_{oc}



Brazil - the **largest mineral reserves of niobium**

Main results

- Study of Nb_2O_5 as hole transport layer

- Origin of hysteresis in perovskite solar cells

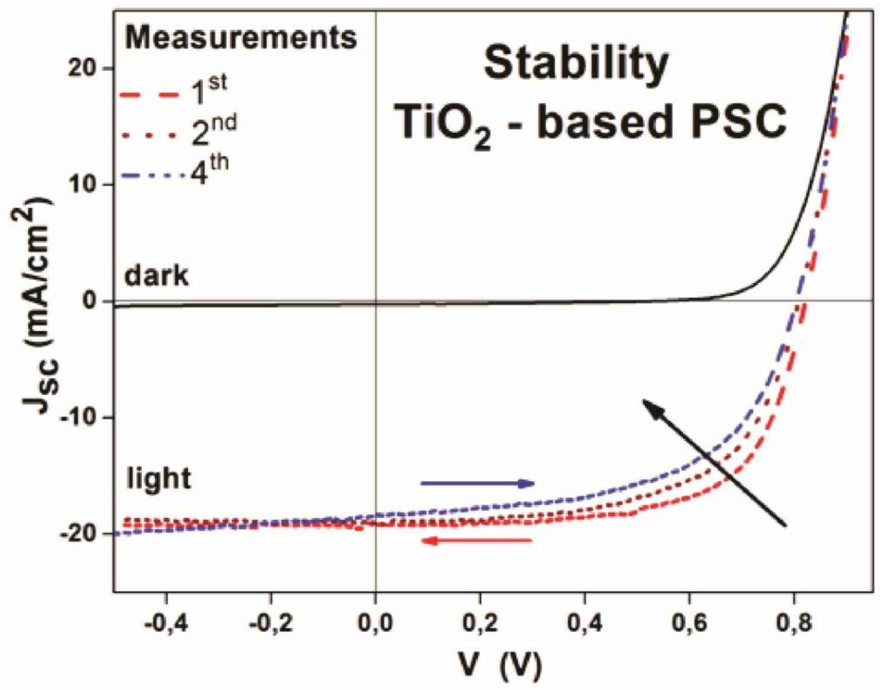
- **Use of different niobium oxide films and its influence on the performance of the solar cells**

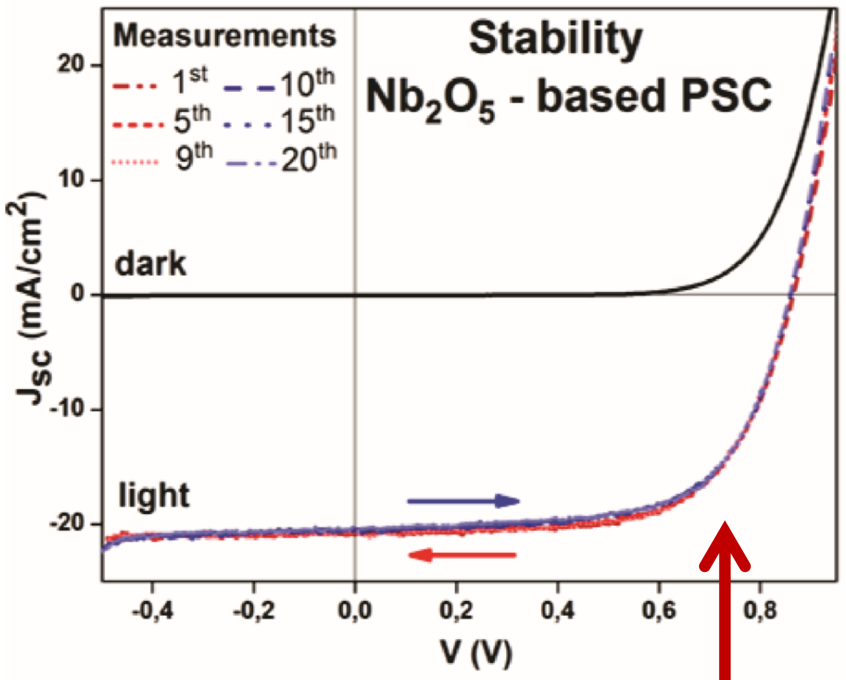
Comparing TiO_2 x Nb_2O_5

TiO_2 based perovskite solar cells				
Measurement	Eff (%)	J (mA/cm^2)	Voc (mV)	FF (%)
1st (Back)	12.01	20.20	962	65.0
4th (Forward)	9.39	19.03	932	52.0

Nb_2O_5 based perovskite solar cells				
Measurement	Eff (%)	J (mA/cm^2)	Voc (mV)	FF (%)
1st (Back)	11.38	19.33	908	64.8
20th (Forward)	11.47	19.21	906	65.9

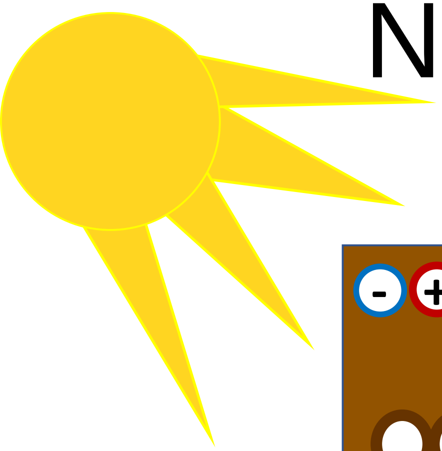
Nb_2O_5 – better stability and no J-V hysteresis

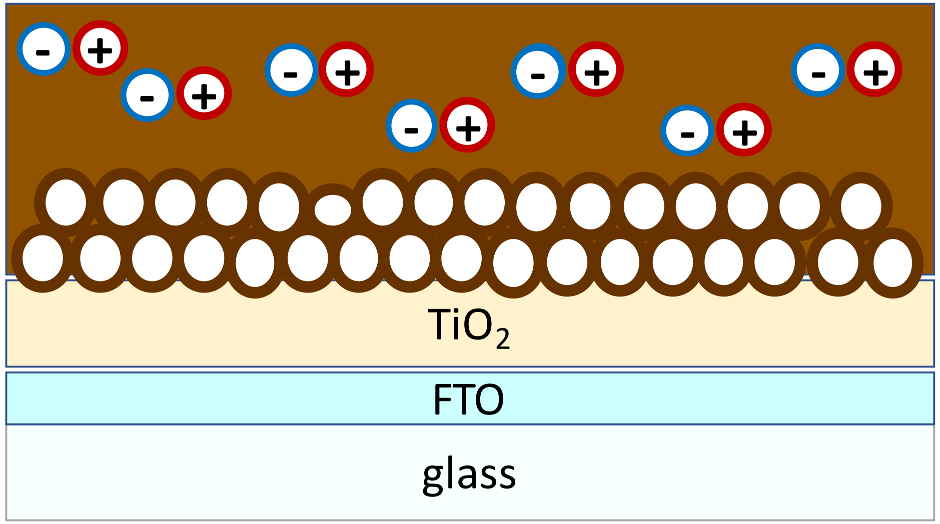


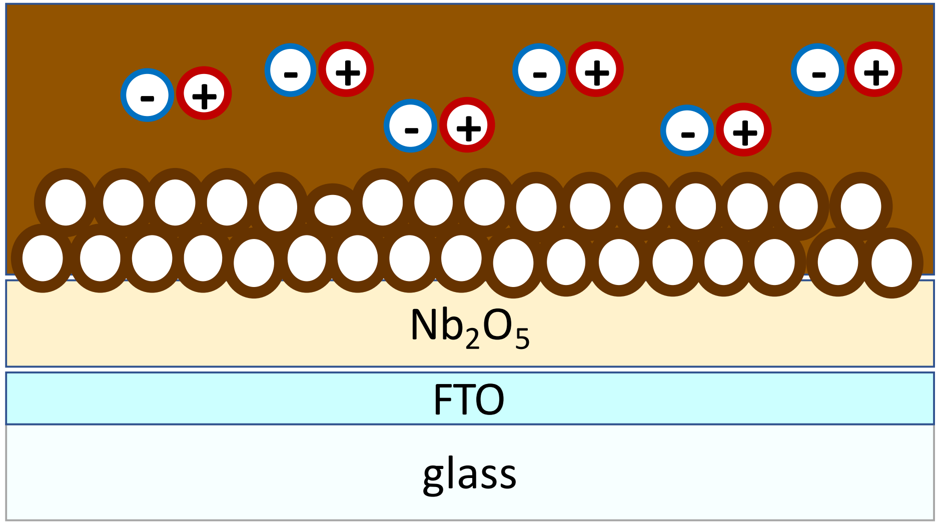


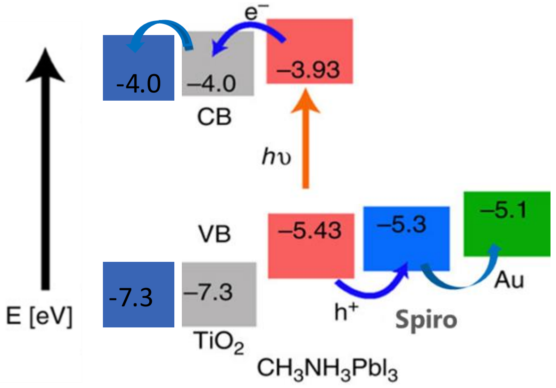
NO HYSTERESIS : BETTER ELECTRON EXTRACTION DUE THE BAND GAP ENGINEERING !

No hysteresis: Better electron extraction

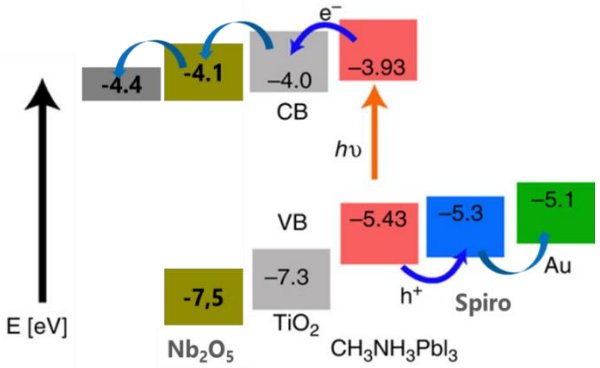








band gap engineering

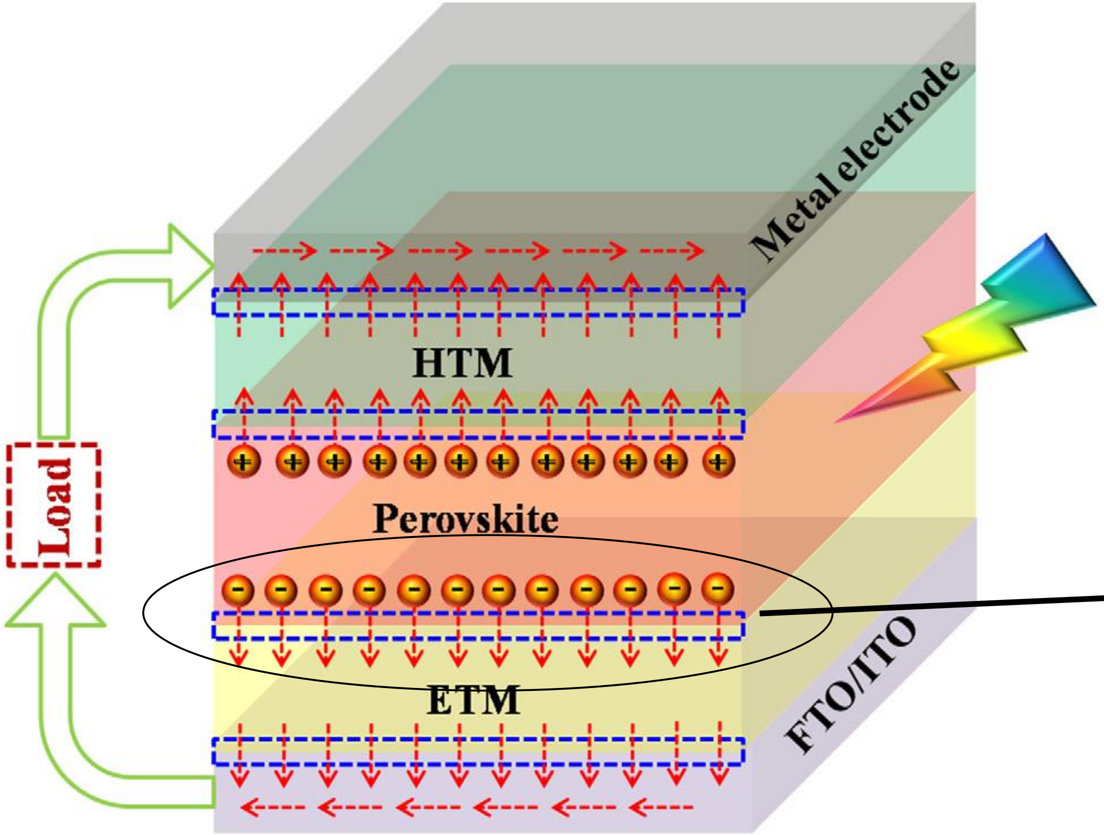


S.L. Fernandes, A.C. Véron, N.F.A. Neto, F.A. Nüesch, et al., Nb_2O_5 hole blocking layer for hysteresis-free perovskite solar cells., Materials Letter, 181 (2016) 103–107. doi: 10.1016/j.matlet.2016.06.018.

High stability: Better electron extraction

Efficient interfacial charge extraction is crucial for mitigating the impact of oxygen-induced degradation.

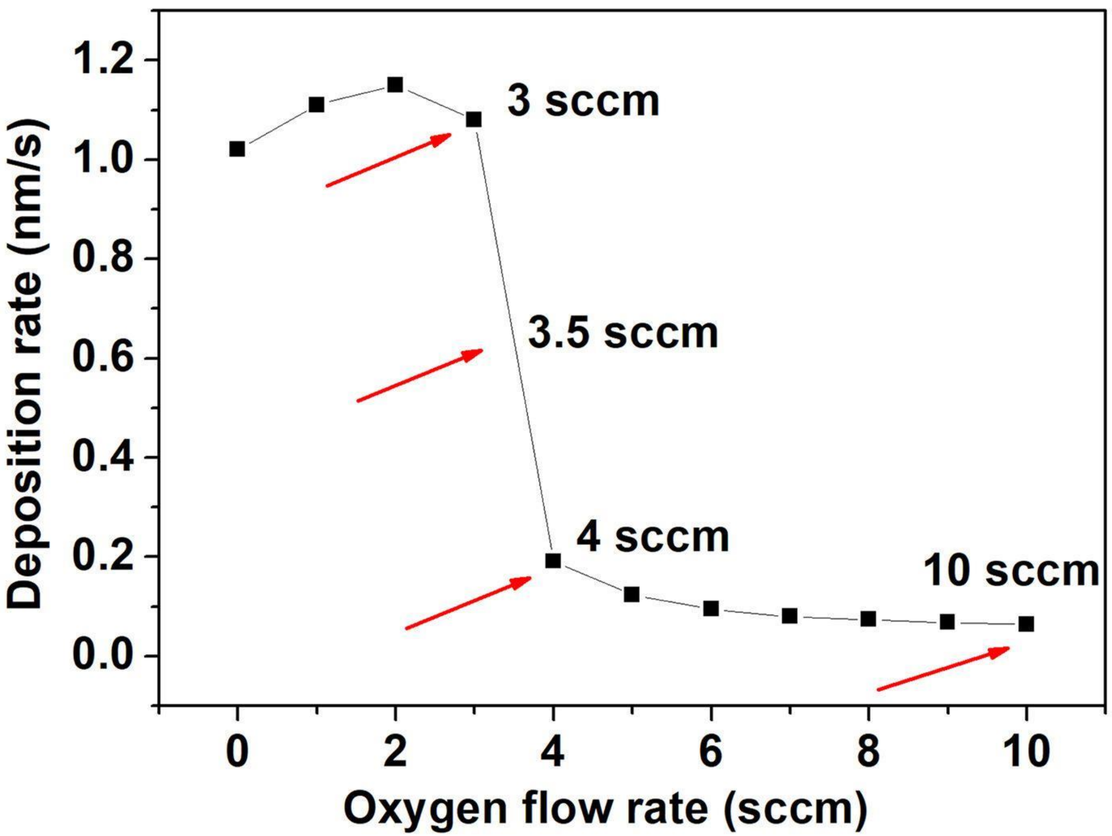
Combination of **non extracted electrons** and **molecular oxygen** decomposed the perovskite materials

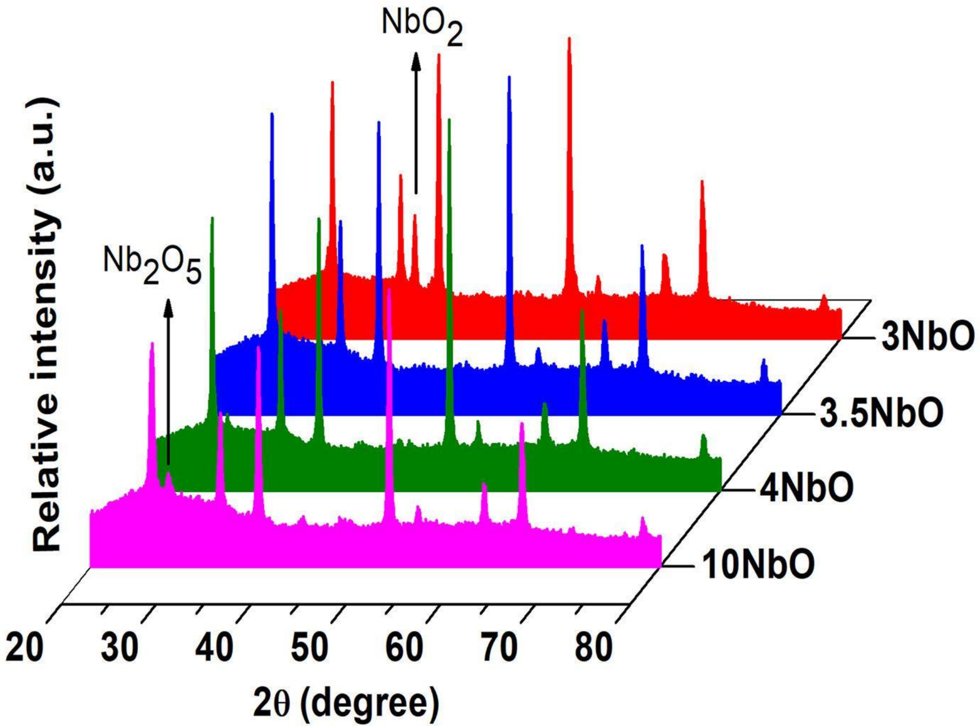


$$O_2 \xrightarrow{e^-} O_2^-$$

$$O_2^- + CH_3NH_3PbI_3 \longrightarrow CH_3NH_2 + PbI_2 + 1/2I_2 + H_2O$$

Exploring the properties of niobium oxide films for perovskite solar cells



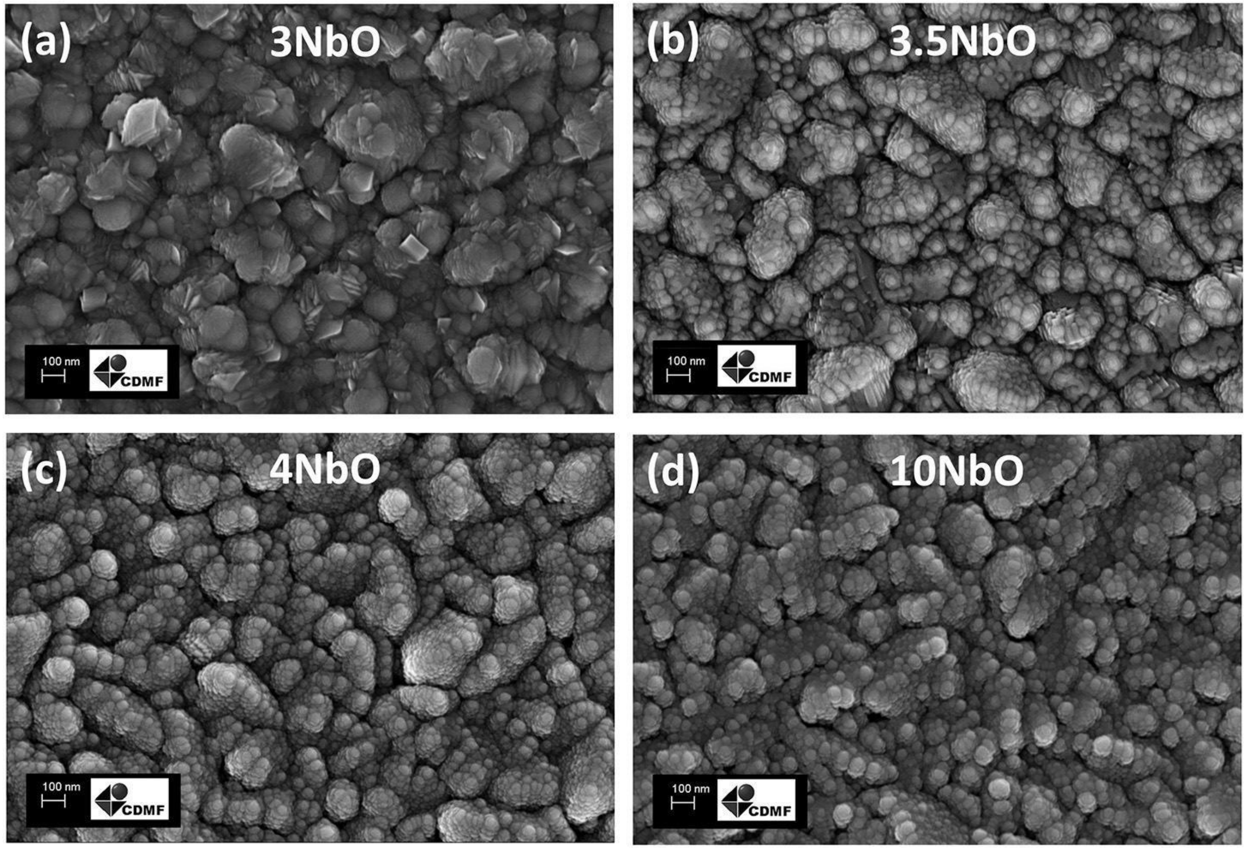


X-Ray Diffraction

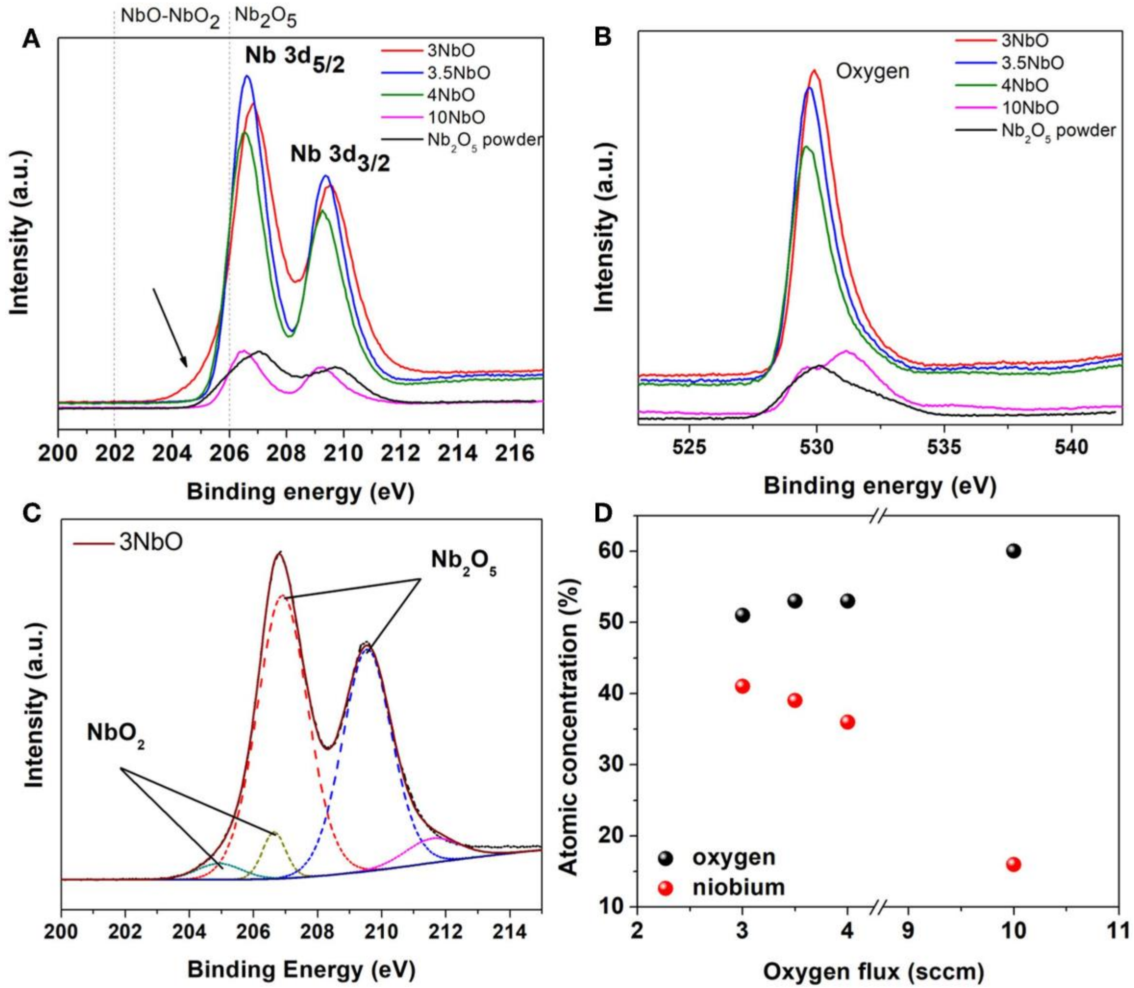
110 nm thick films

S.L. Fernandes et al., Frontiers in Chemistry (2019)

Exploring the properties of niobium oxide films for perovskite solar cells



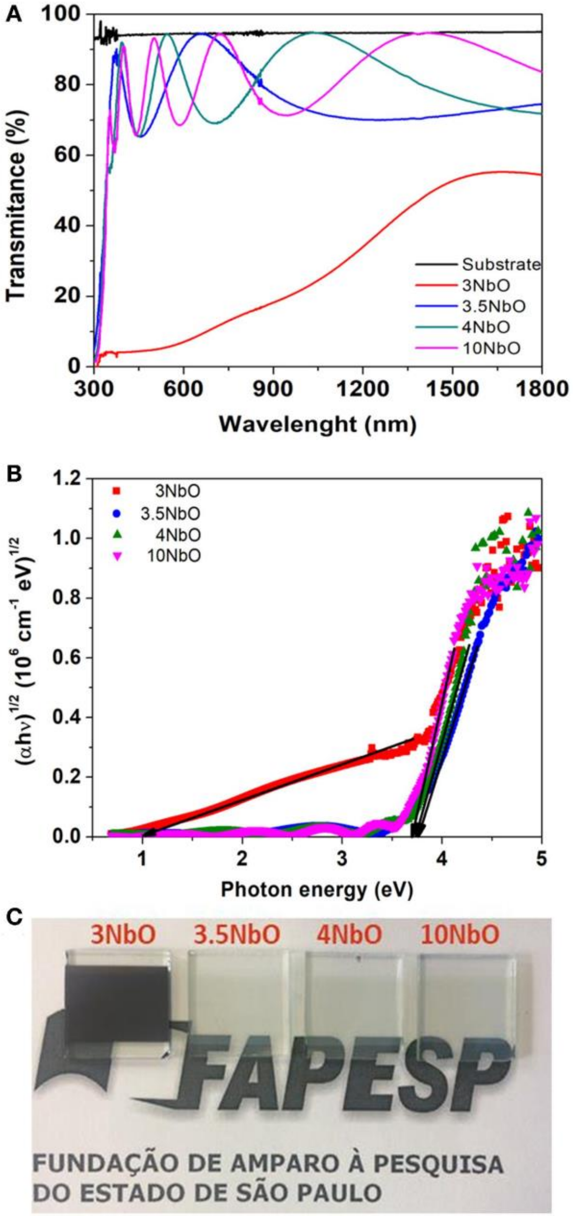
FE-SEM images of the 3NbO (a), 3.5NbO (b), 4NbO (c) and 10 NbO (d).

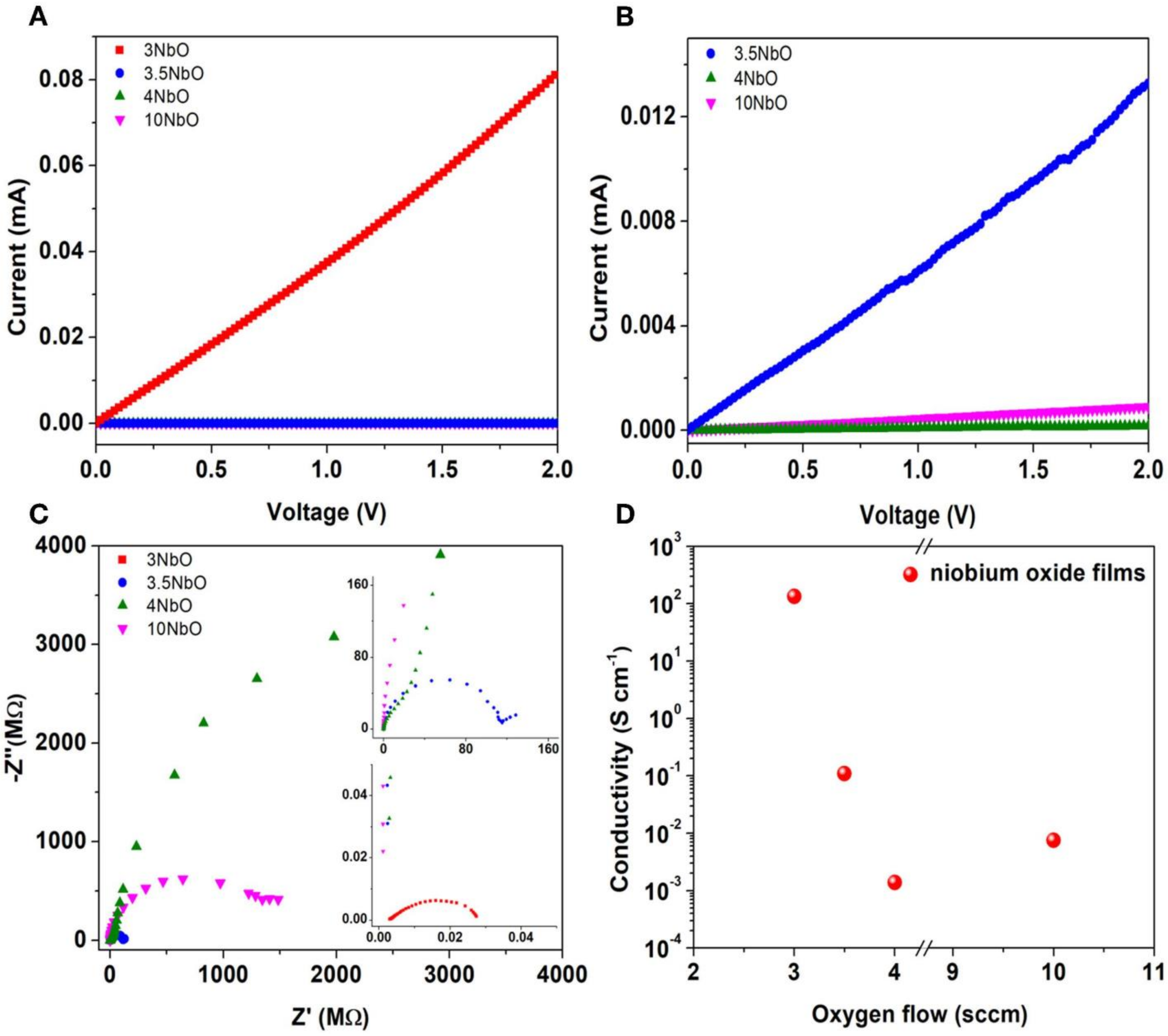


XPS spectra of the niobium oxide films

S.L. Fernandes et al., Frontiers in Chemistry (2019)

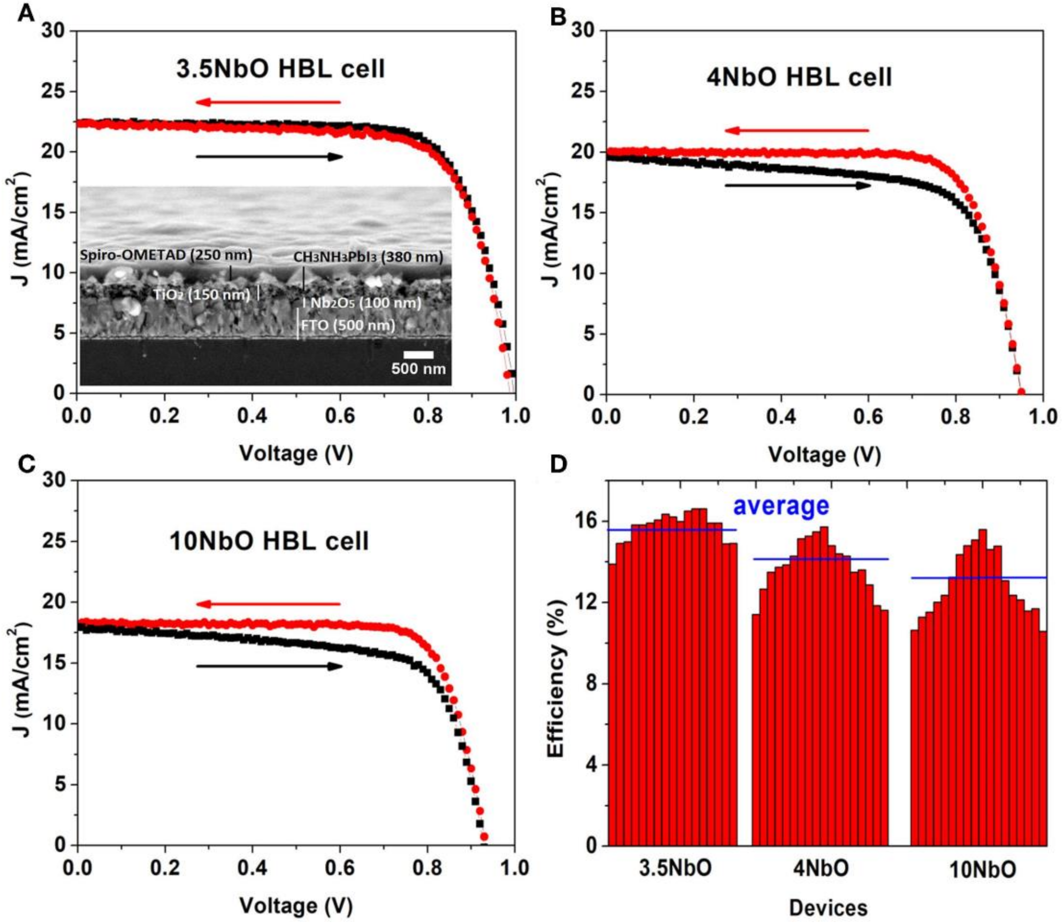
Exploring the properties of niobium oxide films for perovskite solar cells





S.L. Fernandes et al., Frontiers in Chemistry (2019)

Exploring the properties of niobium oxide films for perovskite solar cells



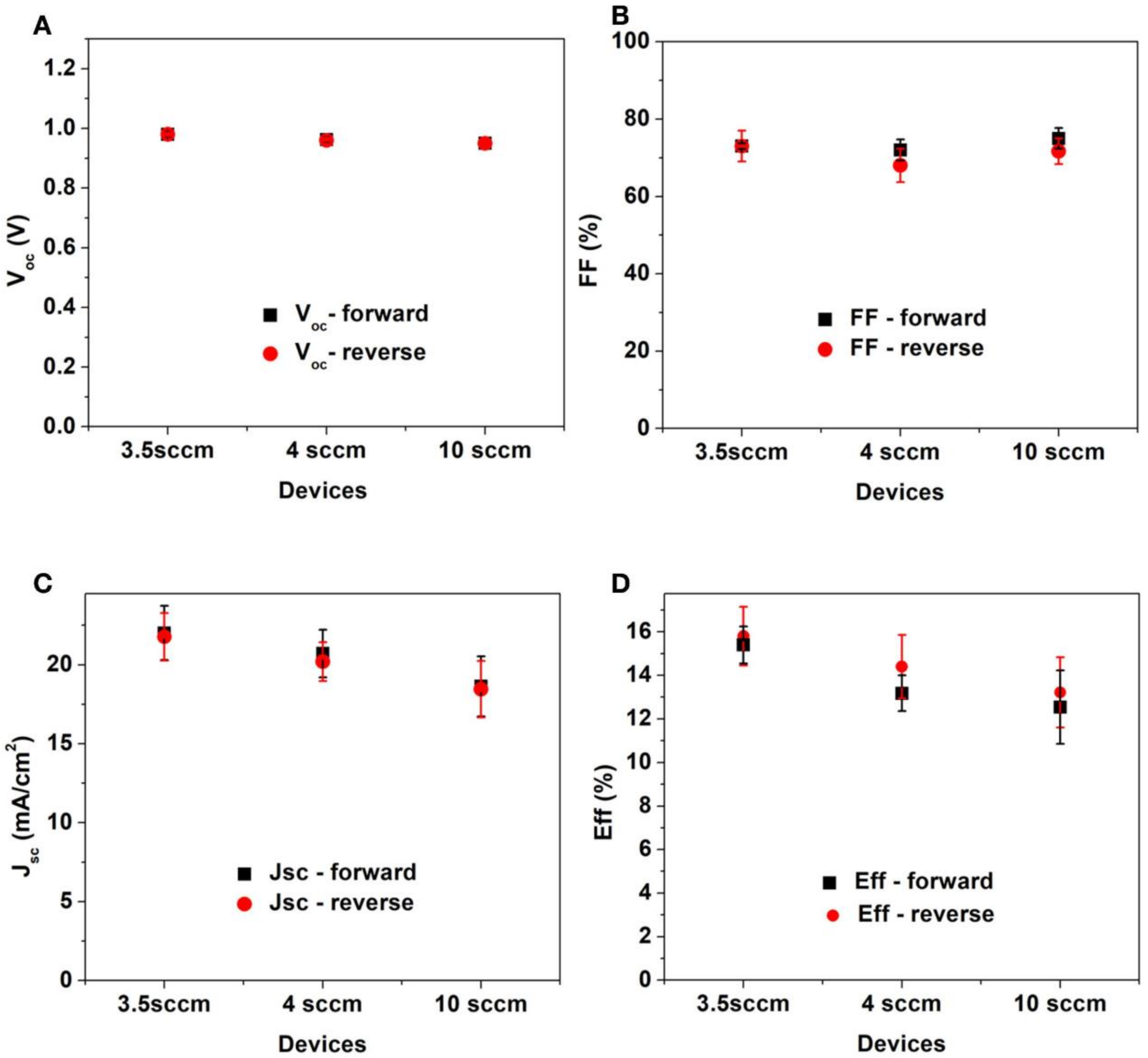
average of 8 cells	Reverse				Forward			
	J_{sc} (mA/cm²)	V_{oc} (V)	FF (%)	Eff (%)	Jsc (mA/cm²)	V_{oc} (V)	FF (%)	Eff (%)
3.5NbO cell	21.77	0.98	73	15.4	22.02	0.98	73	15.8
4NbO cell	20.20	0.96	68	13.2	20.71	0.96	72	14.4
10NbO cell	18.45	0.95	72	12.5	18.63	0.95	75	13.2

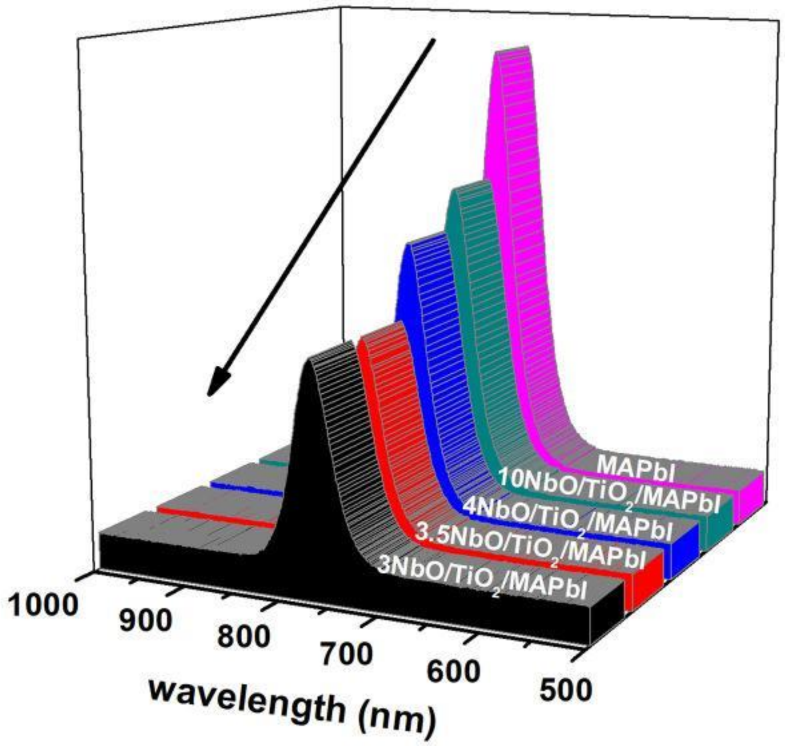
High performance of 3.5NbO based solar cells

S.L. Fernandes et al., Frontiers in Chemistry (2019)

S.L. Fernandes et al., Frontiers in Chemistry (2019)

Exploring the properties of niobium oxide films for perovskite solar cells





PL photoluminescence

S.L. Fernandes et al., Frontiers in Chemistry (2019)

IN-PRESS

Niobium Oxide Films Deposited by Reactive Sputtering Effect of Oxygen Flow Rate

Silvia L. Fernandes[1], Lucas J. Affonço[2], Roberto A. R. Junior[2], José H. D. da Silva[2], Elson Longo[1], Carlos F. de O. Graeff[2]
[1]Chemistry Department, **Federal University of São Carlos (UFSCAR)**, [2]Physics Department, School of Sciences, **São Paulo State University (UNESP)**

ALL

Thank you!

Silvia Leticia Fernandes (CSEM, Brazil)

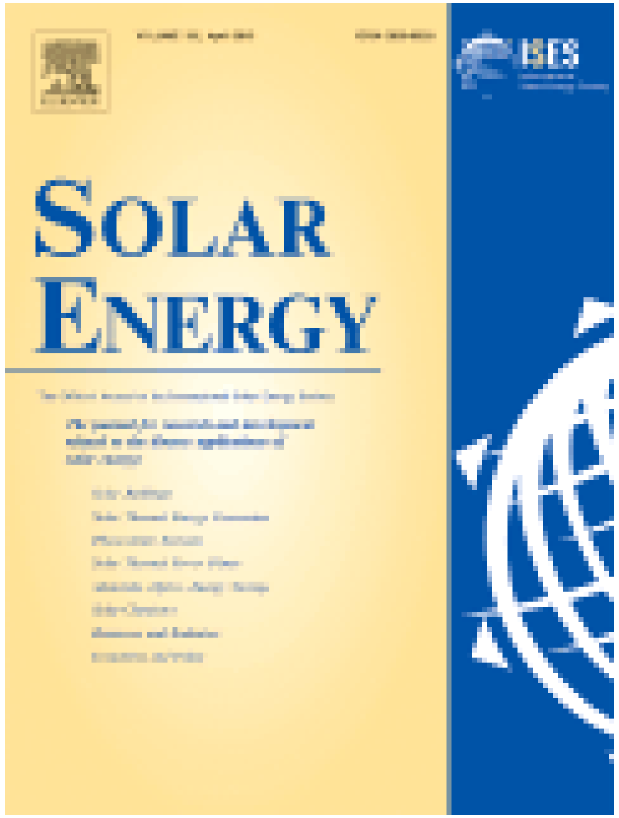
Luiz Gustavo Simão Albano (CNPEM, Brazil)

Lucas Jorge Affonço (FC-UNESP)

José Humberto Dias da Silva (FC-UNESP)

Anna C.Véron (EMPA, Switzerland)

Frank A. Nüesch (EMPA, Switzerland)



Our Group

ABOUT UNESP

Infrastructure:

- 62,021,627 m2 Total Campus Area.
- 972,158 m2 Construction.
- 34 Schools in 24 Cities.
- 1,900 Laboratories
- 30 Libraries, with over 3.2 million titles.
- 24 Institutes and Study & Service Centres.
- 5 Teaching & Research Farms.
- 3 Veterinary Hospitals.
- 1 State Hospital.
- 3 Campuses with Odontology Service
- Oral Oncology Centre.
- Social Legal Centre
- Odontology Assistance Centre for the handicaped.
- Applied Psychology Centres.

Campus

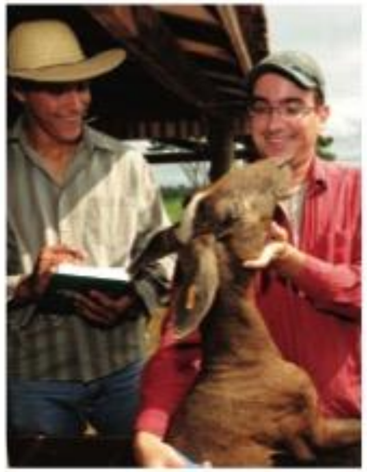
Campus with Graduate Studies

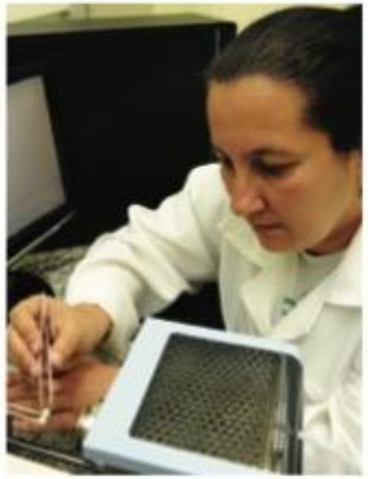
CAMPUS WITH CONCEPTS OF EXCELLENCE

Campuses information:
unesp.br/international/detail/campuses.php

Research

Leadership and Excellence in Research Programs





Animal Science

Aquaculture; Animal Breeding and Genetics; Animal Health; Application of DNA Analysis Tools in Biodiversity, Production and Health of Animals; Reproduction Biotechniques; Molecular Genetics and Genomic Selection; Nutritional Requirements; Production, Management and Conservation Animal Husbandry; Veterinary Public Health and Food Security.

Biotechnology and Health

Industrial and Food Microbiology; Diagnostics Biotechnology, Bioproducts, and Biopharmaceuticals; Medicines Development; Biology, Treatment, Repair and Regeneration of craniofacial tissues; Evaluation and Physiotherapeutic Intervention in Human Systems.

Material Science

Biomaterials; Hybrid Organic-Inorganic materials; Photonic materials; Polymeric materials; Vitreous and Ceramic materials.

Territory Development and Social Movements

Agrarian Issues, Sustainable Agriculture, Traditional Communities and The Labor environment; Rural Education and Territorial Planning; Brazil's and Latin America's Social Movements (UNESCO's Academic Chair). Urbanization and mid-size cities; Networks, Territorial Logics and Social Exclusion; Public Policies, Urban Climate and Sustainable Development.

Theoretical Physics

Few-body Physics, Condensed Matter Physics, General Relativity, Complex Systems, Particle Physics, Cosmology, Quantum Field Theory, Bose-Einstein Condensates, High energy Physics, Astroparticles, String Theory. Since 2010, it hosts the South American Institute for Scientific Research, a branch of the prestigious International Center for Theoretical Physics in Trieste.

INTERNATIONAL RANKINGS

THE World University Rankings Young — 2017: Brazil 1-2; World 151-200 (1.200)

THE World University Rankings Latin America — 2017: Brazil 12

THE World University Rankings — 2018: World 601-800 (1.500)

QS World University Rankings Top 50 Under 50 — 2018: Brazil 1; World 71-80

QS University Rankings Latin America — 2016: Latin America 12

QS University Rankings BRICS — 2016: BRICS 36