Centro de Investigación y de Estudios Avanzados del IPN
Departamento de Física Aplicada
Grupo de Celdas Solares

Tecnología para la fabricación de celdas solares de alta eficiencia basadas en películas delgadas de CdS/CdTe

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Proyecto apoyado por Fordecyt-Conacyt "Creación del laboratorio de energías renovables del sureste (LENERSE)"

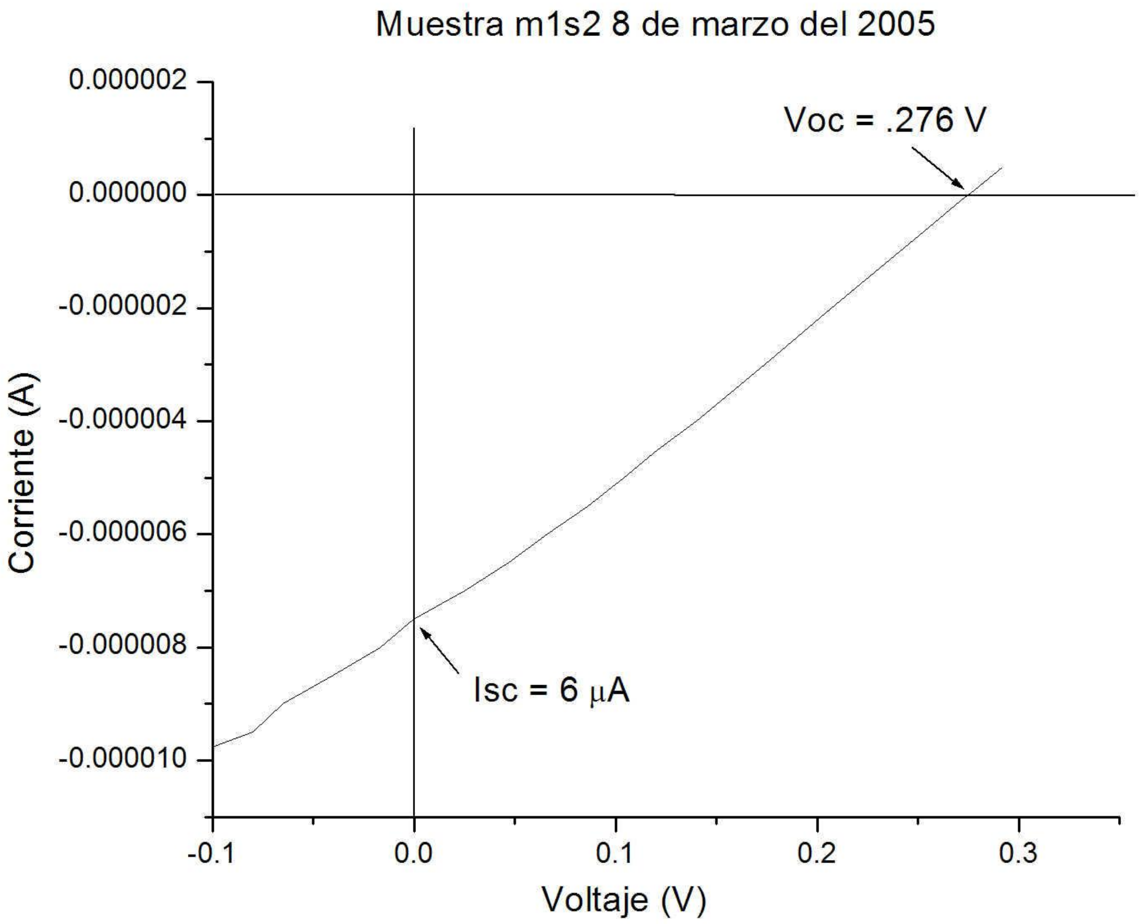
Subproyecto Energía Solar

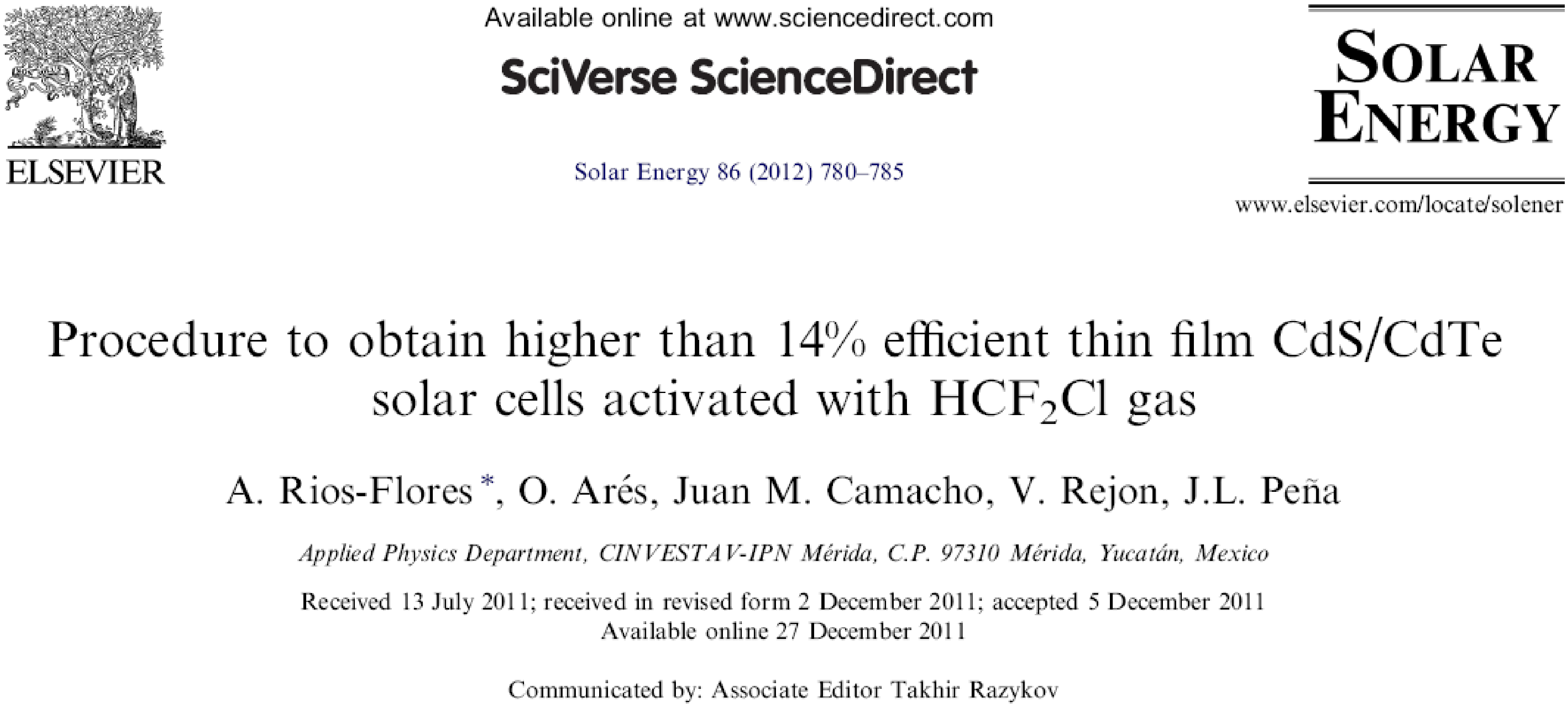
Coordinador:
Dr. Juan Luis Peña
CINVESTAV-IPN
MERIDA

Outline

- Introduction
- Our CdS/CdTe solar cells
- Experimental results
- Future work and conclusion

Celdas fabricadas en el 2005





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Procedure to obtain higher than 14% efficient thin film CdS/CdTe solar cells activated with HCF_2Cl gas

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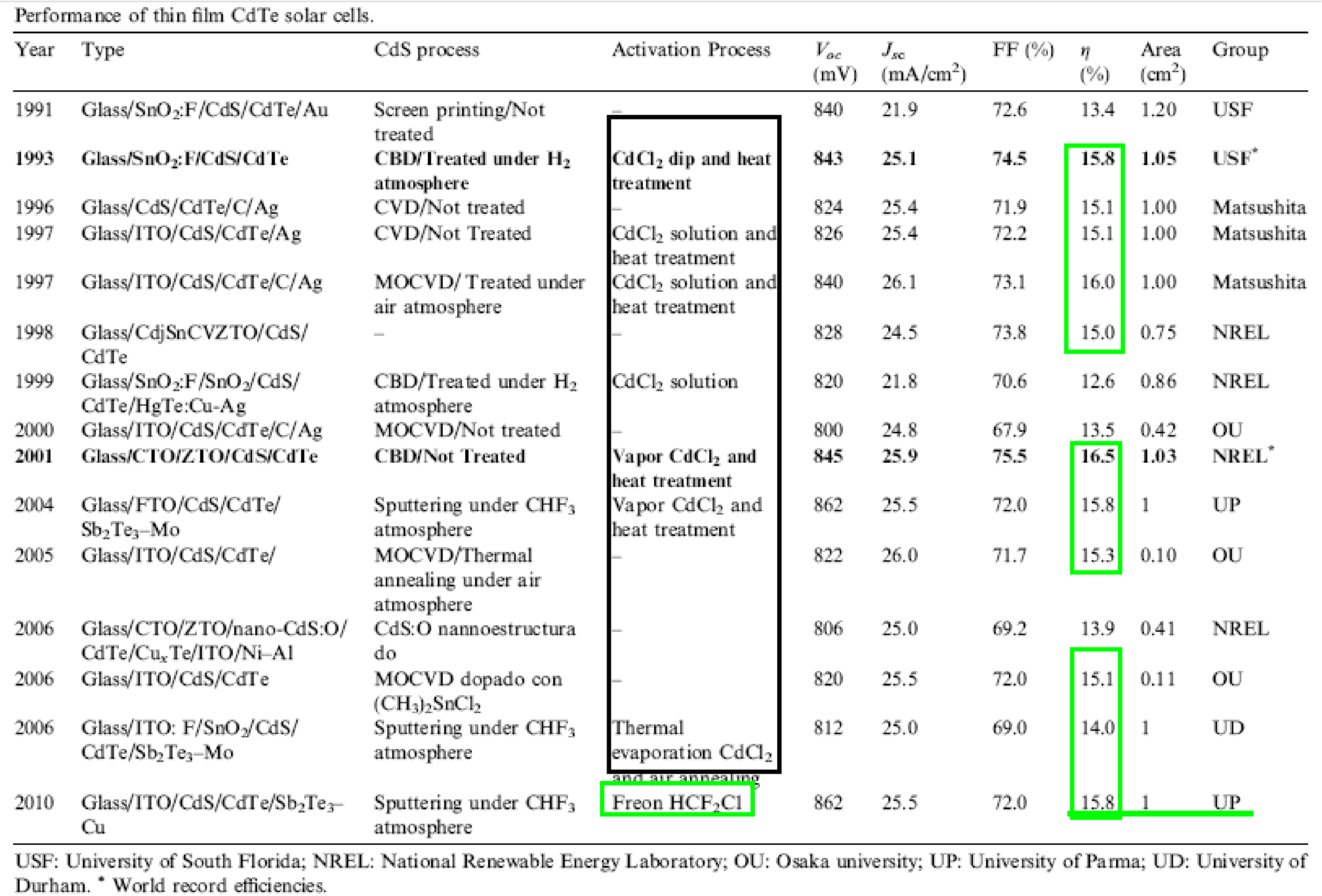


Performance of thin film CdTe solar cells.

Year	Type	CdS process	Activation Process	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	η (%)	Area (cm^2)	Group
1991	Glass/SnO$_2$:F/CdS/CdTe/Au	Screen printing/Not treated	–	840	21.9	72.6	13.4	1.20	USF
1993	**Glass/SnO$_2$:F/CdS/CdTe**	**CBD/Treated under H$_2$ atmosphere**	**CdCl$_2$ dip and heat treatment**	**843**	**25.1**	**74.5**	**15.8**	**1.05**	**USF***
1996	Glass/CdS/CdTe/C/Ag	CVD/Not treated	–	824	25.4	71.9	15.1	1.00	Matsushita
1997	Glass/ITO/CdS/CdTe/Ag	CVD/Not Treated	CdCl$_2$ solution and heat treatment	826	25.4	72.2	15.1	1.00	Matsushita
1997	Glass/ITO/CdS/CdTe/C/Ag	MOCVD/ Treated under air atmosphere	CdCl$_2$ solution and heat treatment	840	26.1	73.1	16.0	1.00	Matsushita
1998	Glass/CdjSnCVZTO/CdS/ CdTe	–	–	828	24.5	73.8	15.0	0.75	NREL
1999	Glass/SnO$_2$:F/SnO$_2$/CdS/ CdTe/HgTe:Cu-Ag	CBD/Treated under H$_2$ atmosphere	CdCl$_2$ solution	820	21.8	70.6	12.6	0.86	NREL
2000	Glass/ITO/CdS/CdTe/C/Ag	MOCVD/Not treated	–	800	24.8	67.9	13.5	0.42	OU
2001	**Glass/CTO/ZTO/CdS/CdTe**	**CBD/Not Treated**	**Vapor CdCl$_2$ and heat treatment**	**845**	**25.9**	**75.5**	**16.5**	**1.03**	**NREL***
2004	Glass/FTO/CdS/CdTe/ Sb$_2$Te$_3$–Mo	Sputtering under CHF$_3$ atmosphere	Vapor CdCl$_2$ and heat treatment	862	25.5	72.0	15.8	1	UP
2005	Glass/ITO/CdS/CdTe/	MOCVD/Thermal annealing under air atmosphere	–	822	26.0	71.7	15.3	0.10	OU
2006	Glass/CTO/ZTO/nano-CdS:O/ CdTe/Cu$_x$Te/ITO/Ni–Al	CdS:O nannoestructura do	–	806	25.0	69.2	13.9	0.41	NREL
2006	Glass/ITO/CdS/CdTe	MOCVD dopado con (CH$_3$)$_2$SnCl$_2$	–	820	25.5	72.0	15.1	0.11	OU
2006	Glass/ITO: F/SnO$_2$/CdS/ CdTe/Sb$_2$Te$_3$–Mo	Sputtering under CHF$_3$ atmosphere	Thermal evaporation CdCl$_2$ and air annealing	812	25.0	69.0	14.0	1	UD
2010	Glass/ITO/CdS/CdTe/Sb$_2$Te$_3$–Cu	Sputtering under CHF$_3$ atmosphere	Freon HCF$_2$Cl	862	25.5	72.0	15.8	1	UP

USF: University of South Florida; NREL: National Renewable Energy Laboratory; OU: Osaka university; UP: University of Parma; UD: University of Durham. * World record efficiencies.

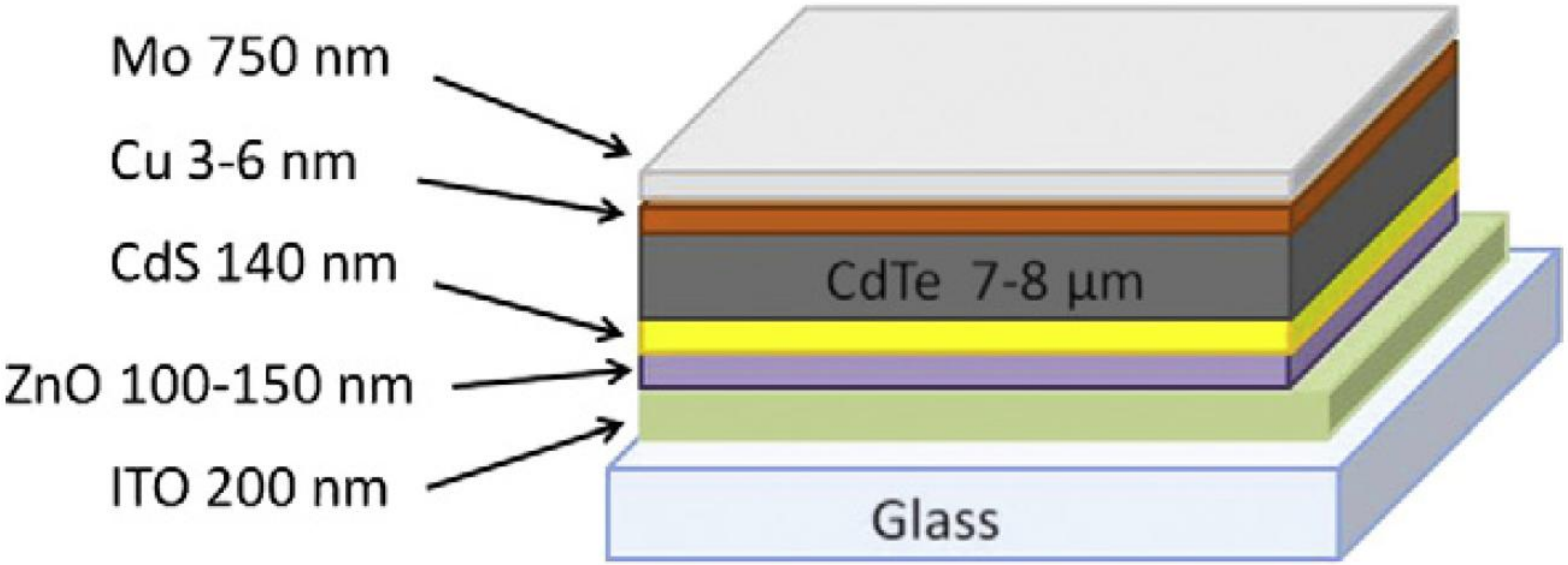
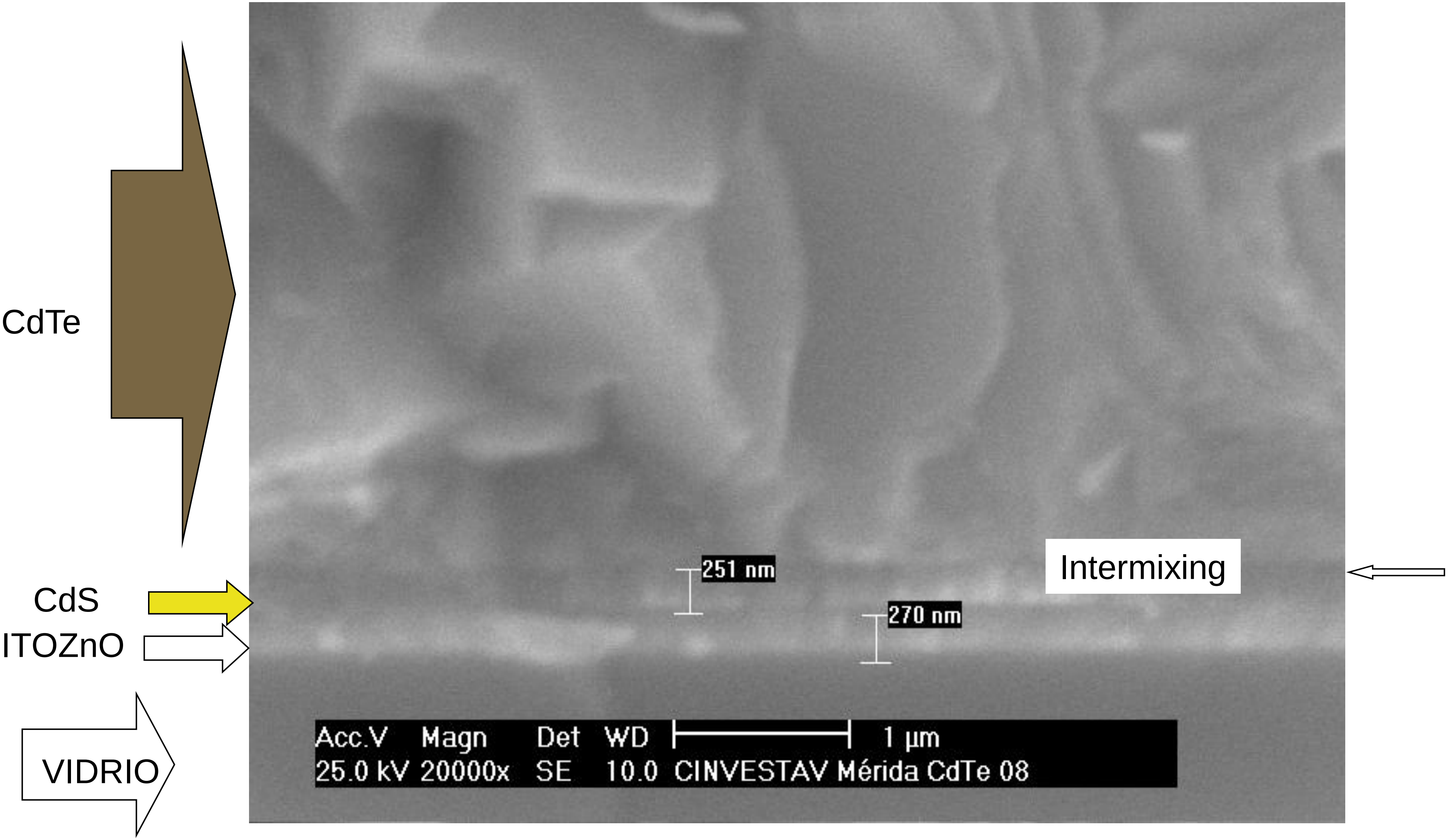


Fig. 1. The structure of CdTe/CdS solar cells.



CdTe

CdS

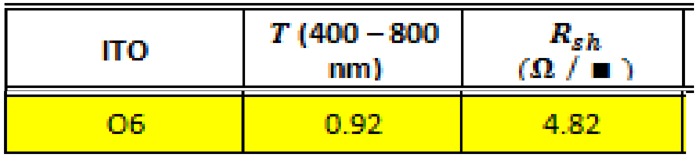
ITOZnO

VIDRIO

Intermixing

Our CdS/CdTe solar cell process (2011)

- ITO comercial
- Our ITO (2012)



ITO	T (400 – 800 nm)	R_{sh} (Ω / ■)
06	0.92	4.82

- ZnO (100-120 nm) by sputtering
- CdS (130-160 nm) by sputtering without intentional treatment
- CdTe (8-10 µm) by CSS, gas mixed Ar/O2
- Activation: $CHClF_2$ + Ar
- Cu/Mo (5 nm / 750 nm) by sputtering.
- Soaking: depending on EQE spectra

Optimizing the growth parameters of ITO for application in solar cells CdS/CdTe

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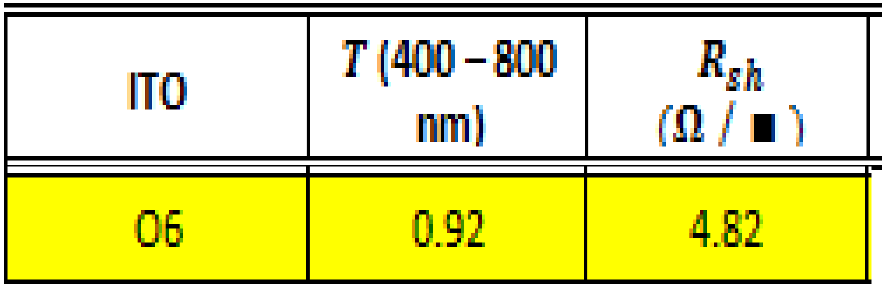

ITO	T (400 – 800 nm)	R_{sh} (Ω / ■)
06	0.92	4.82

- **Our optimized ITO thin film was deposited by using the following conditions: Ts=550 °C, RF-power=100 W, Pressure of Ar= 15 mTorr, Time of growth= 7 min.**
- **Our ITO thin film had better electrical, optical and morphological characteristics than commercial ITO**

V International Conference on Surfaces, Materials and Vacuum
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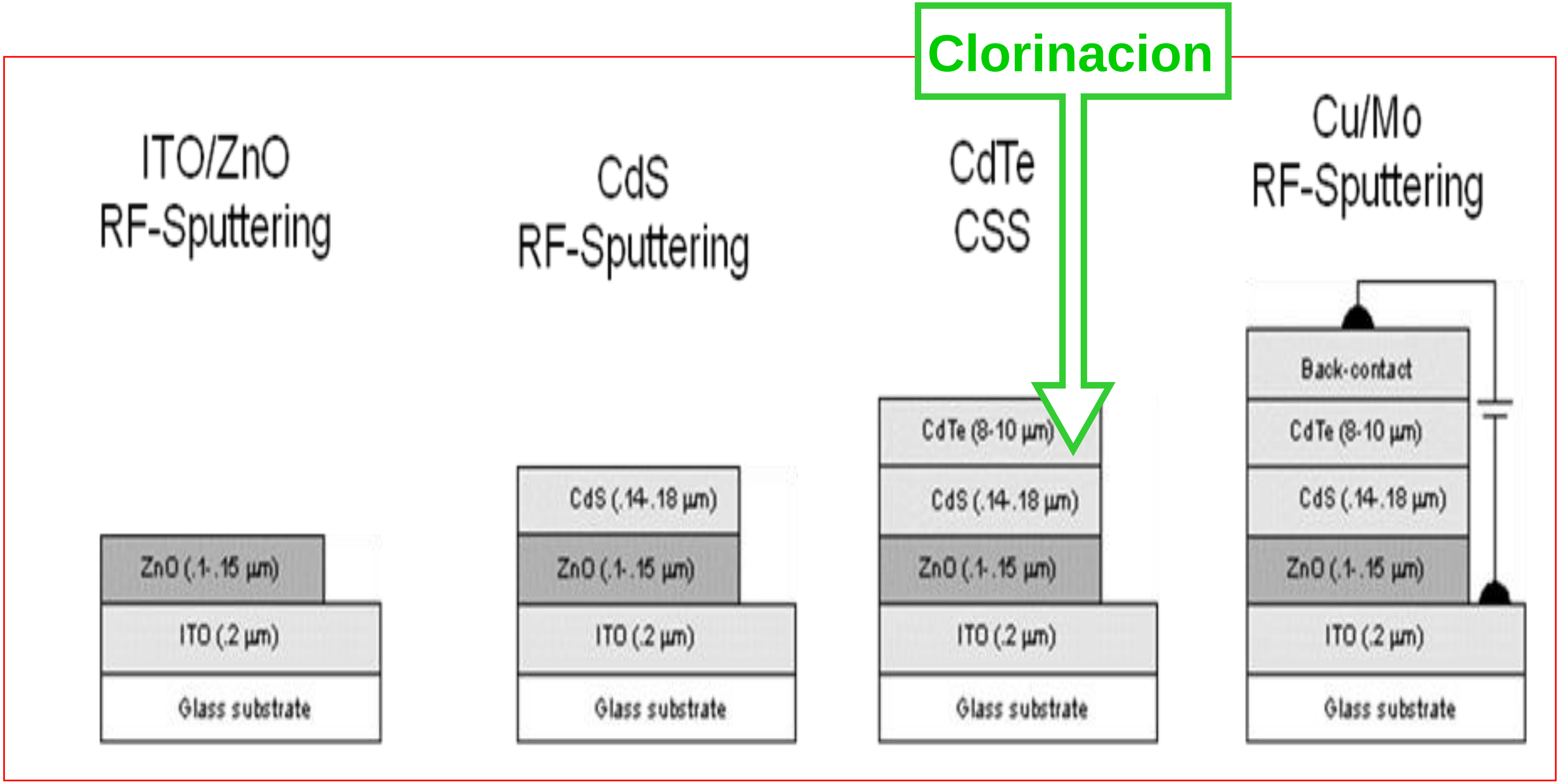
Our CdS/CdTe solar cell process



ITO/ZnO RF-Sputtering

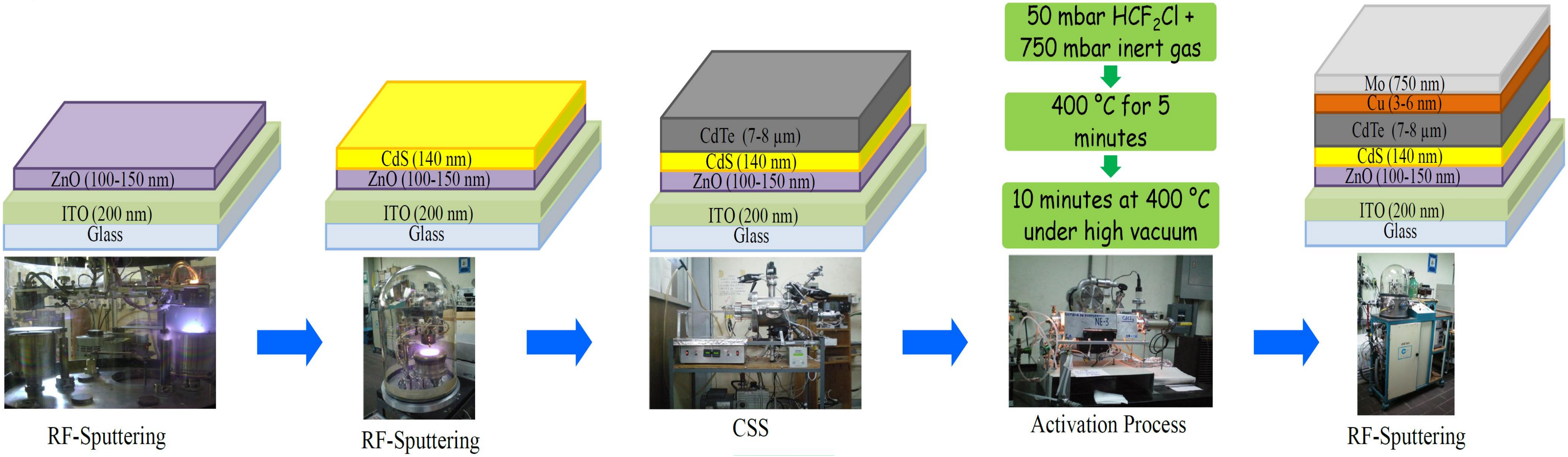
CdS RF-Sputtering

CdTe CSS

Clorinacion

Cu/Mo RF-Sputtering

The procedure to manufacture the CdS/CdTe solar cell is show below.



ZnO (100-150 nm)
ITO (200 nm)
Glass
RF-Sputtering

CdS (140 nm)
ZnO (100-150 nm)
ITO (200 nm)
Glass
RF-Sputtering

CdTe (7-8 μm)
CdS (140 nm)
ZnO (100-150 nm)
ITO (200 nm)
Glass
CSS

50 mbar HCF_2Cl + 750 mbar inert gas

400 °C for 5 minutes

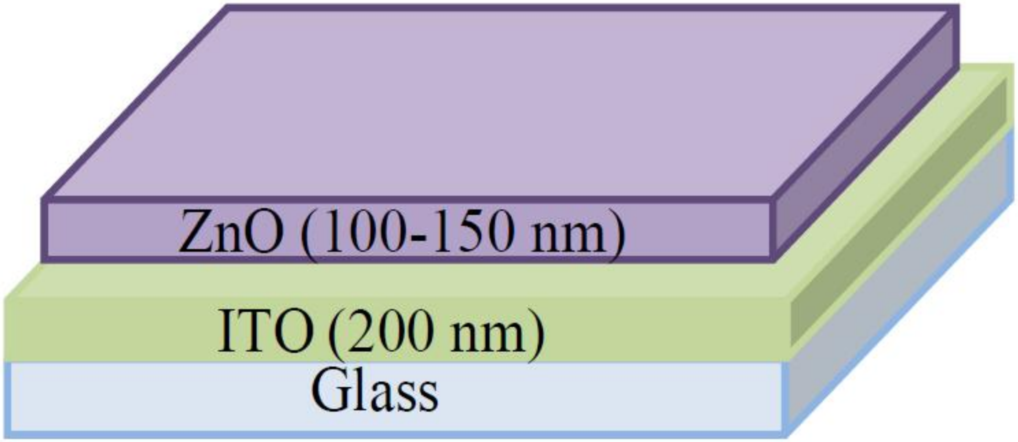
10 minutes at 400 °C under high vacuum

Activation Process

Mo (750 nm)
Cu (3-6 nm)
CdTe (7-8 μm)
CdS (140 nm)
ZnO (100-150 nm)
ITO (200 nm)
Glass
RF-Sputtering

The procedure to manufacture the CdS/CdTe solar cell is show below.

ITO/ZnO



RF-Sputtering

The procedure to manufacture the CdS/CdTe solar cell is show below.

CdS

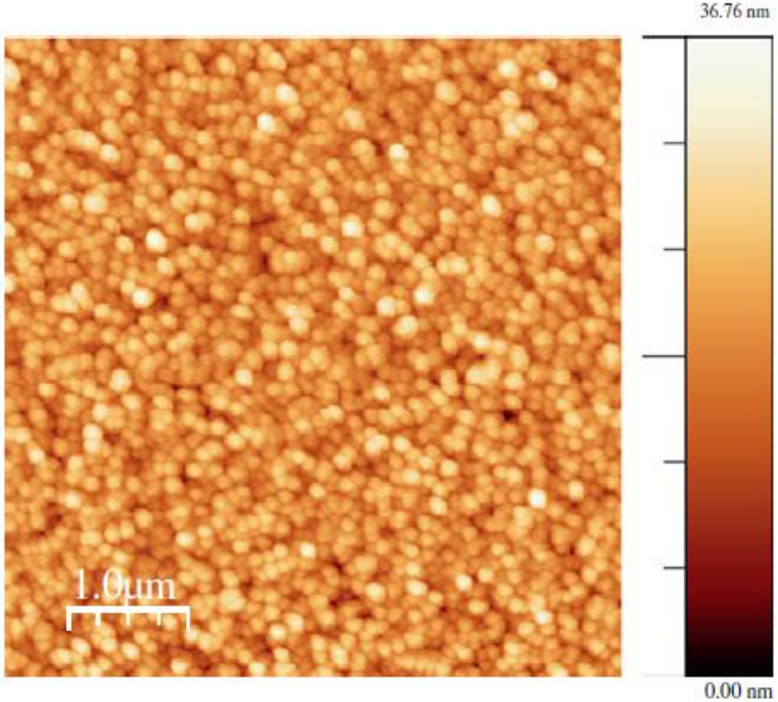
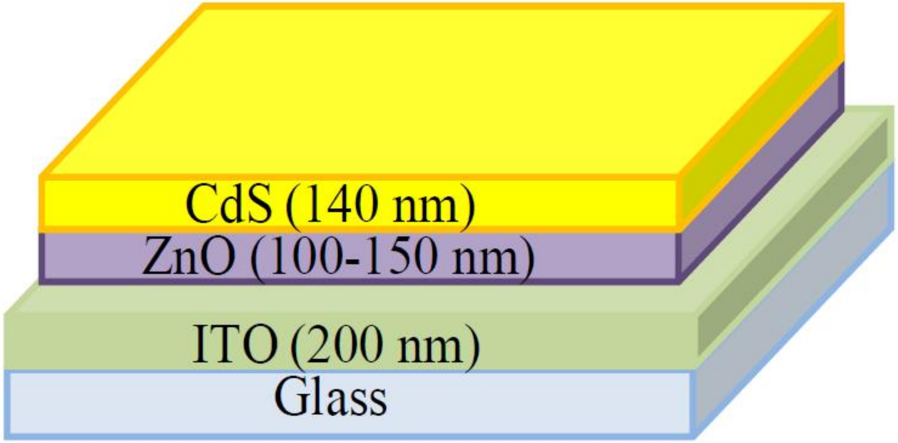


Fig. 3. 5 × 5 µm^2 AFM image of the CdS film.



RF-Sputtering

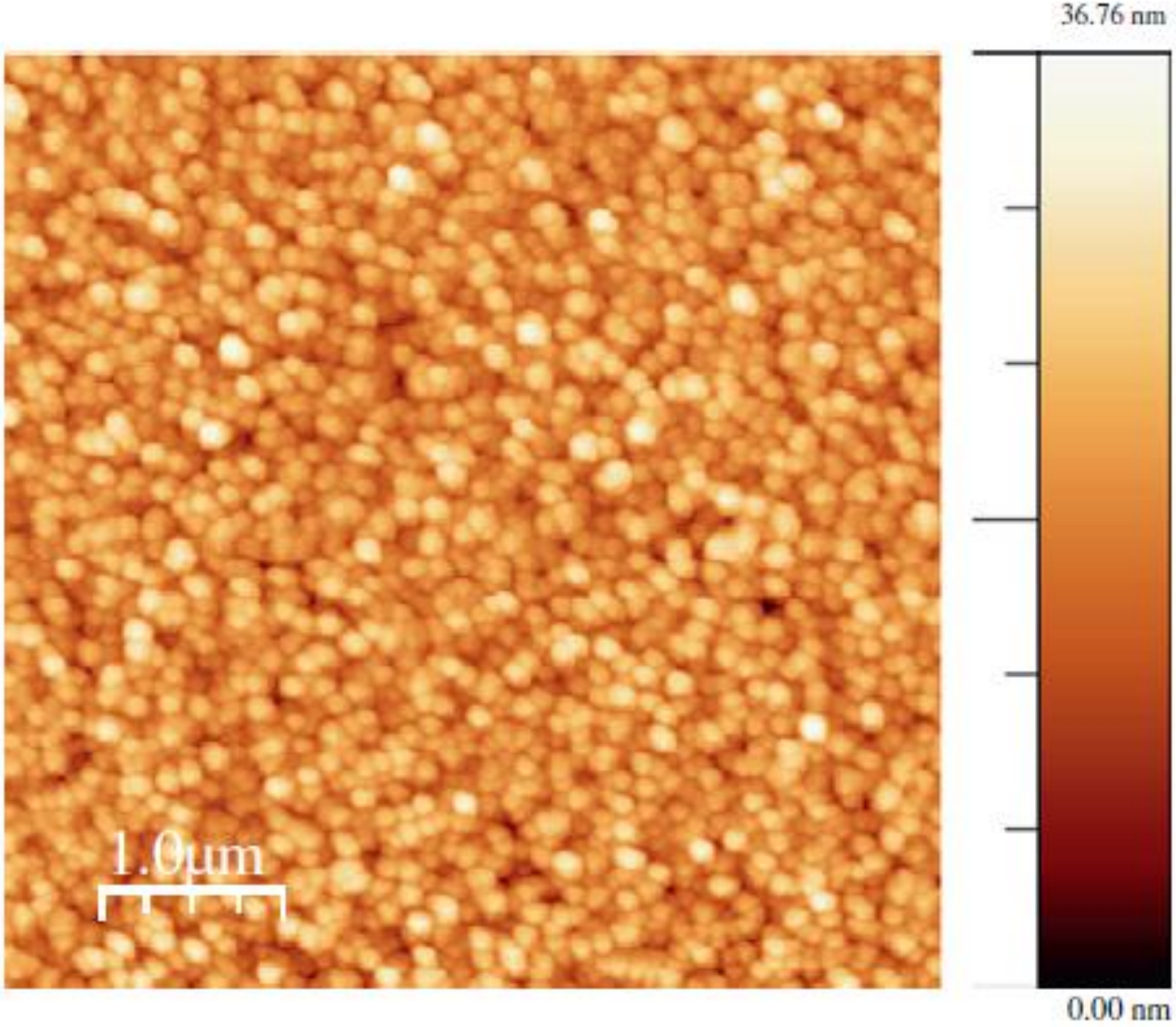


Fig. 3. 5 × 5 μm² AFM image of the CdS film.

Thin films of CdS: O deposited by RF-sputtering technique§

Mariely Loeza Poot[1], Inés Riech[1], Víctor Rejon[2],Juan Luis Peña Chapa[2]

[1] Facultad de Ingeniería, Universidad Autónoma de Yucatán, Av. Industrial no contaminantes por anillo periférico norte s/n Apdo. Postal 150 Cordemex, Mérida, Yucatán, México.
[2] Applied Physics Department, CINVESTAV-IPN Km. 6 Antigua Carretera a Progreso, Mérida, Yucatán, 97310, México

○ Optical properties

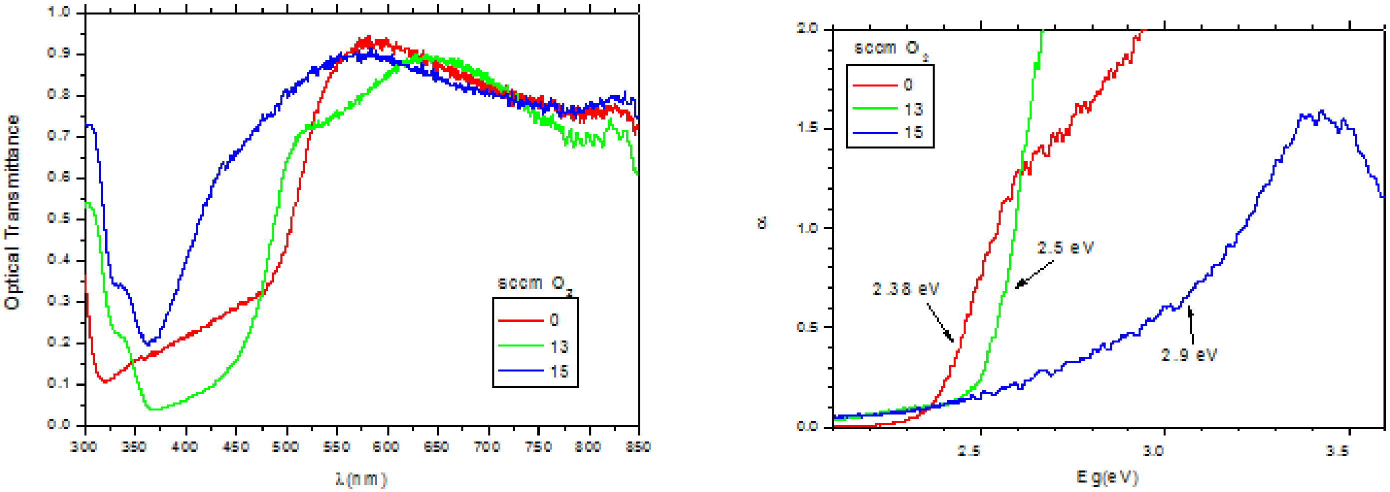


Figure 2. Influence of O_2 on the optical transmittance and band gap of CdS film.

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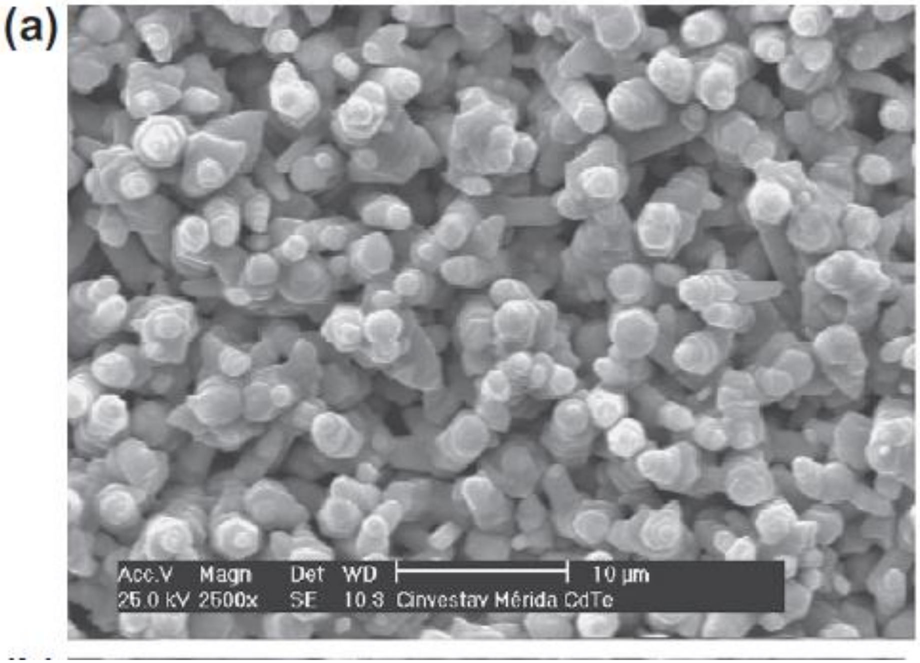
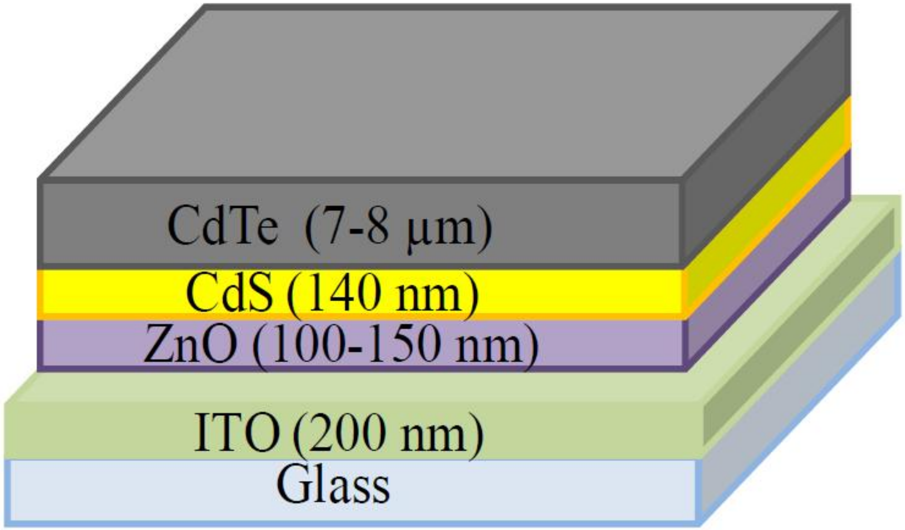
The procedure to manufacture the CdS/CdTe solar cell is show below.

CdTe



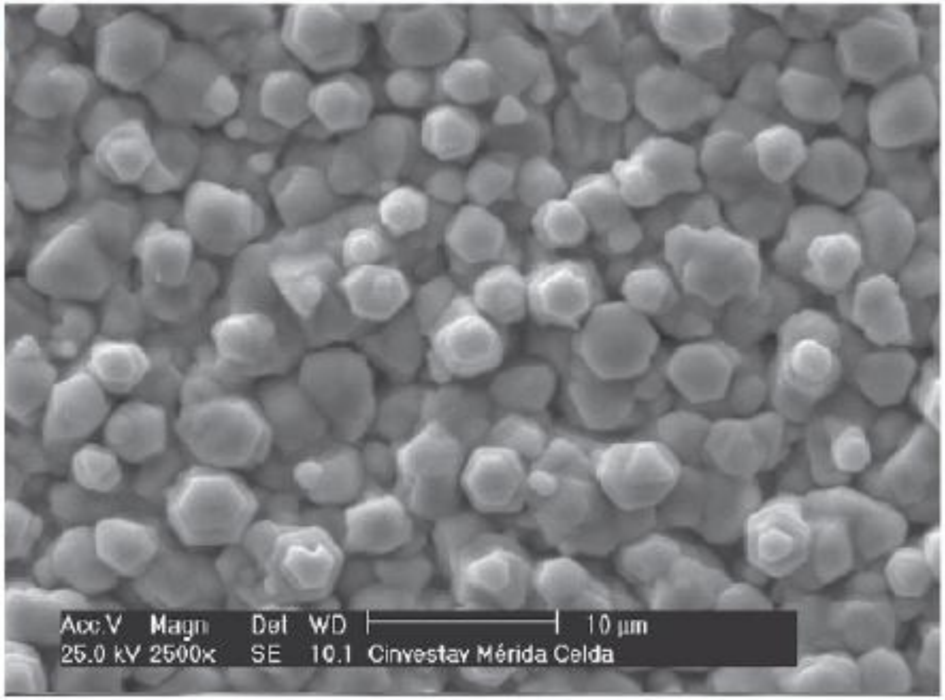


CSS

The procedure to manufacture the CdS/CdTe solar cell is show below.

Activation Process

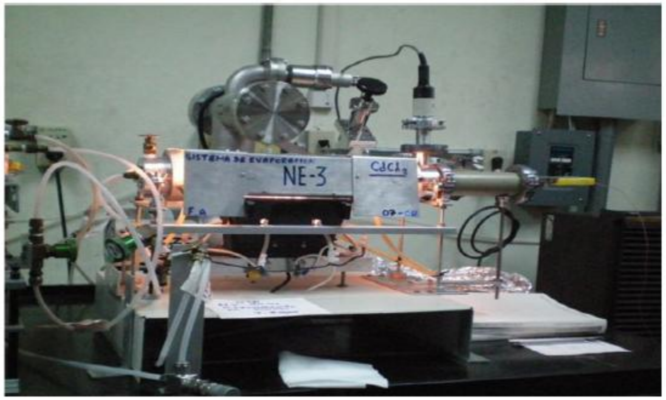
(b)



50 mbar HCF_2Cl + 750 mbar inert gas

400 °C for 5 minutes

10 minutes at 400 °C under high vacuum



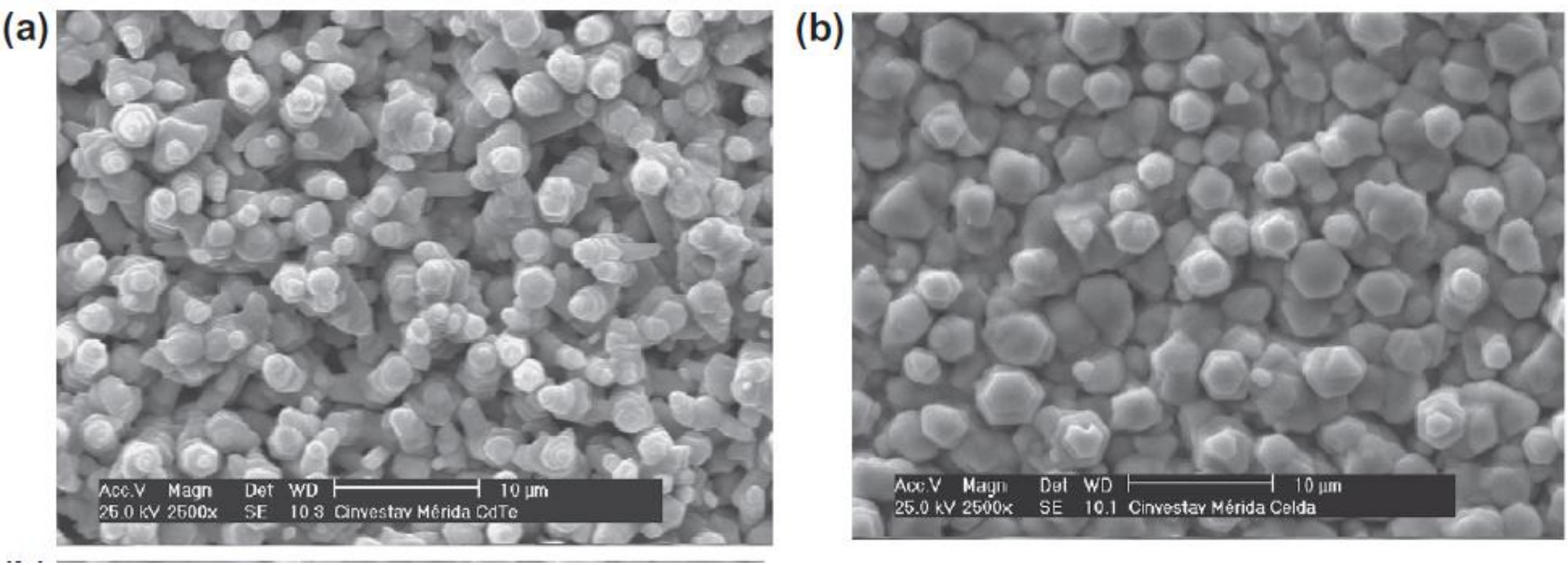


Fig. 4. SEM photos of the surface of CdTe films: (a) morphology of an untreated CdTe film deposited by the CSS method and (b) morphology of the same film after thermal treatment in Ar + HCF_2Cl atmosphere at a temperature of 400 °C for 5 min.

Comparación del uso en el proceso de activación de la celda solar de

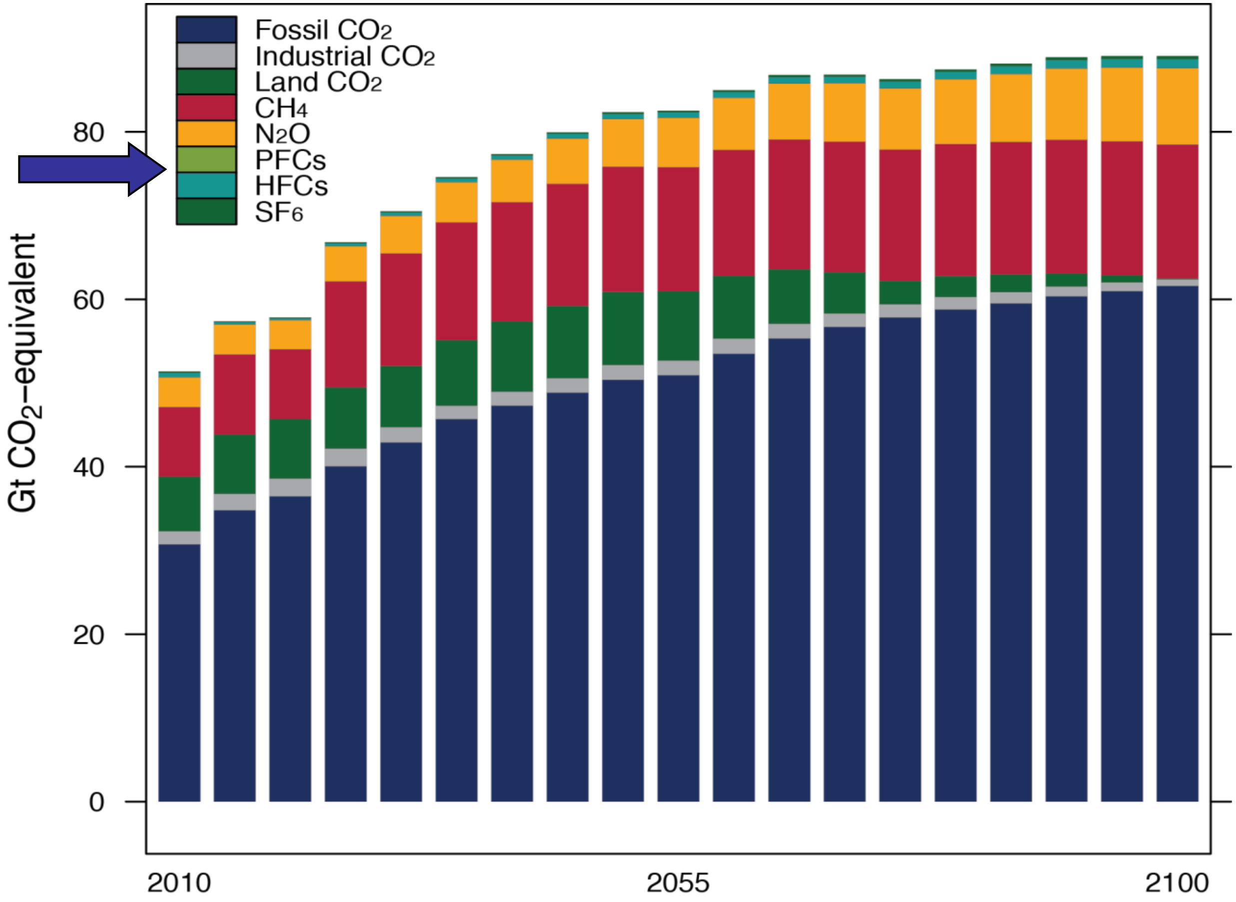
Freon HCF_2Cl

vs

$CdCl_2$

Uso de
Freon HCF_2Cl
Impactos al medio ambiente

Global Greenhouse Gas Emissions



Compuestos con cloro y flúor (CFC, HCFC, HFC)
Perfluorocarbonos (PFCs) formula C_nF_{2n+2}

Chlorofluorocarbon was found mostly in refrigerators, aerosol cans and air conditioners. But since the Montreal Protocol the use of CFCs has practically been eliminated. Cooling systems that use this compound now use HCFCs which causes less damage to the ozone layer

Actualmente estamos probado gases para la activación de la celda solar que contienen cloro y que son mas amigables con el medio ambiente

Cadmium dichloride ($CdCl_2$)

OVERVIEW OF POTENTIAL HAZARDS

V.M. Fthenakis

Table 2. Some Hazardous Materials used in Current PV Manufacturing

Material	Source	TLV-TWA1 (ppm)	STEL2 (ppm)	IDLH3 (ppm)	ERPG2 4 (ppm)	Critical Effects
Cadmium compounds	CdTe and CdS deposition $CdCl_2$ treatment	0.01 mg/m3 (dust) 0.002 mg/m3 (fumes)	-	-	NA	Cancer, kidney

Effects of long-term or repeated exposure

The substance may have effects on the kidneys and lungs.
This may result in kidney impairment and tissue lesions.
This substance is carcinogenic to humans.

ENVIRONMENTAL DATA:

The substance is toxic to aquatic organisms.
Bioaccumulation of this chemical may occur in plants.
It is strongly advised not to let the chemical enter into the environment.

CdTe surface modification in CdS/CdTe solar cell activated with $CHClF_2$-O_2 gas

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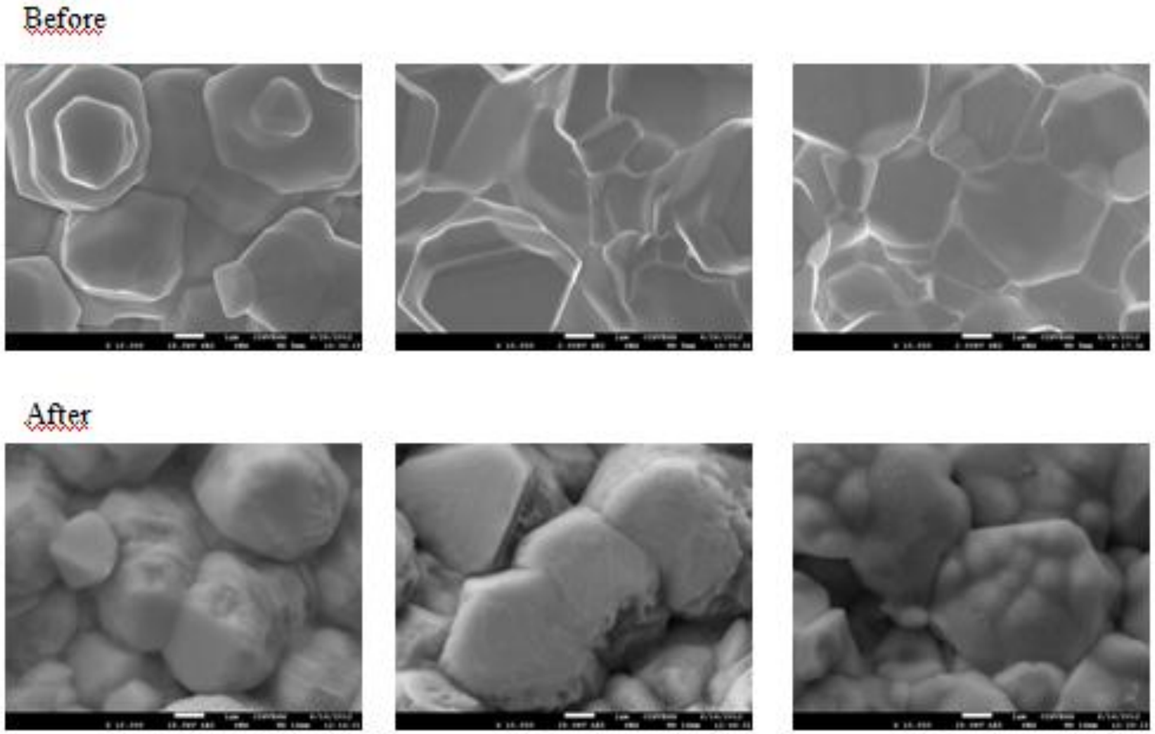
[2]Materials Science Laboratory, Faculty of Engineering, University of Yucatán, Mérida, Yucatán, México.


Before

After

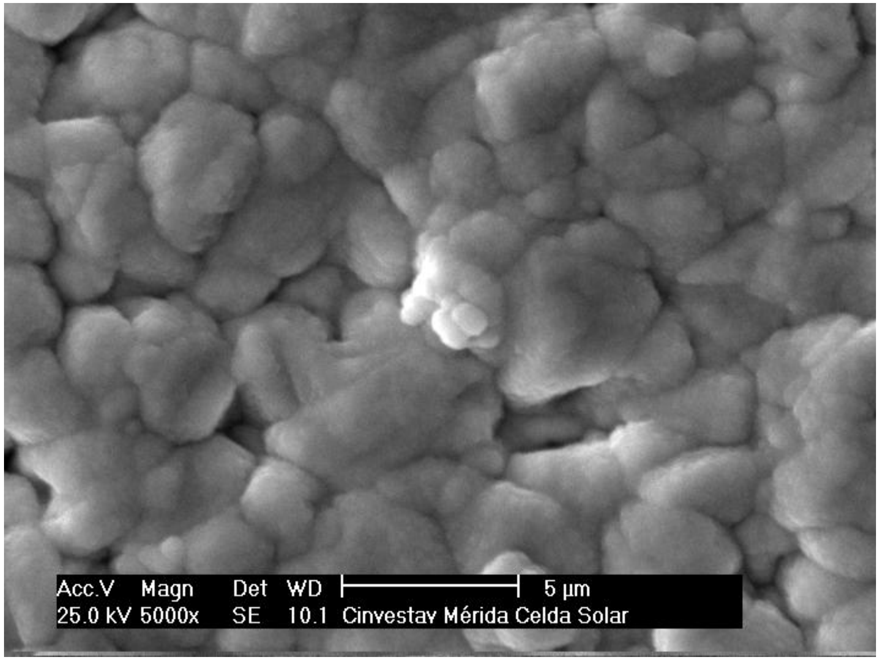
Ar   Ar + $CHClF_2$ Ar + O_2 + $CHClF_2$

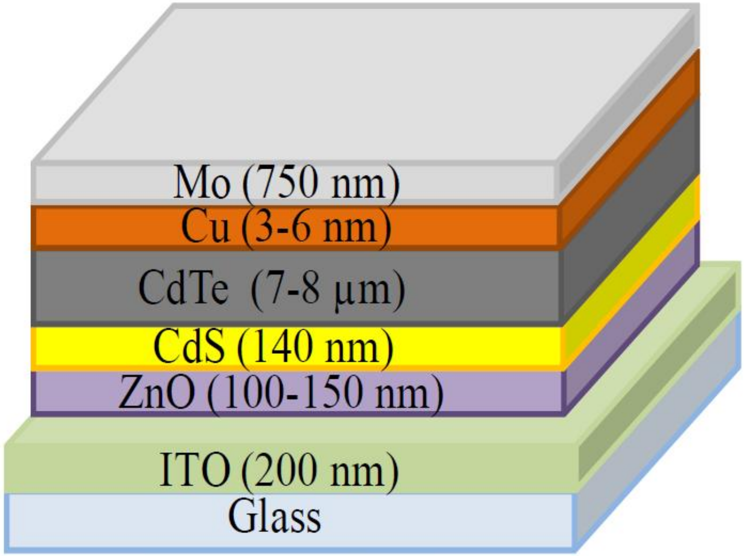
FIG 4. SEM images of solar cells CdS/CdTe before and after the activation process.

38th
IEEE Photovoltaic Specialists Conference
June 3-8, 2012
Austin, Texas

The procedure to manufacture the CdS/CdTe solar cell is show below.

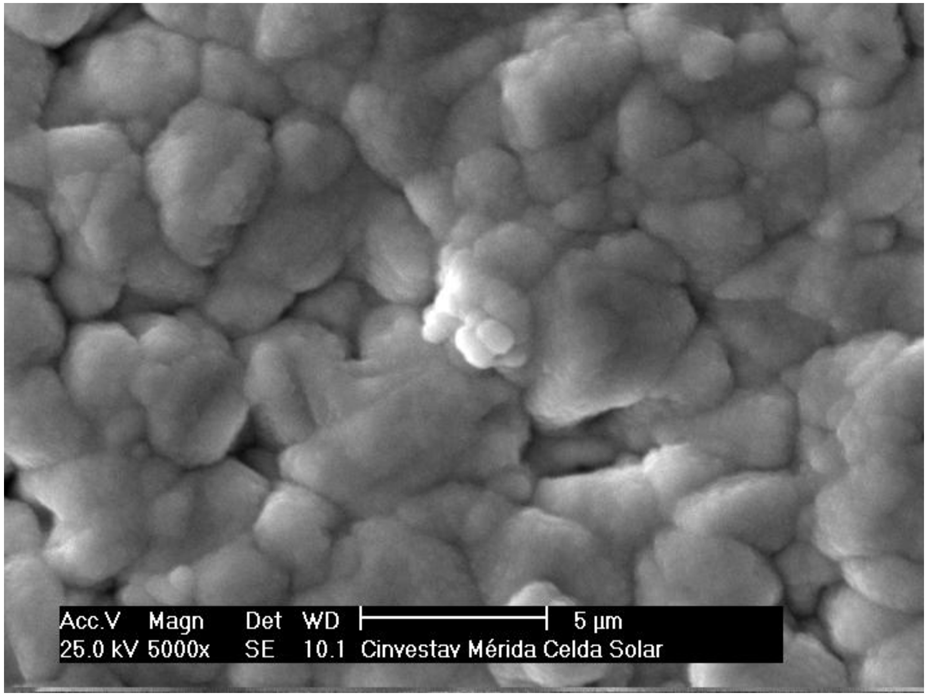
Cu/Mo





RF-Sputtering

Grain size of CdS/CdTe solar cell

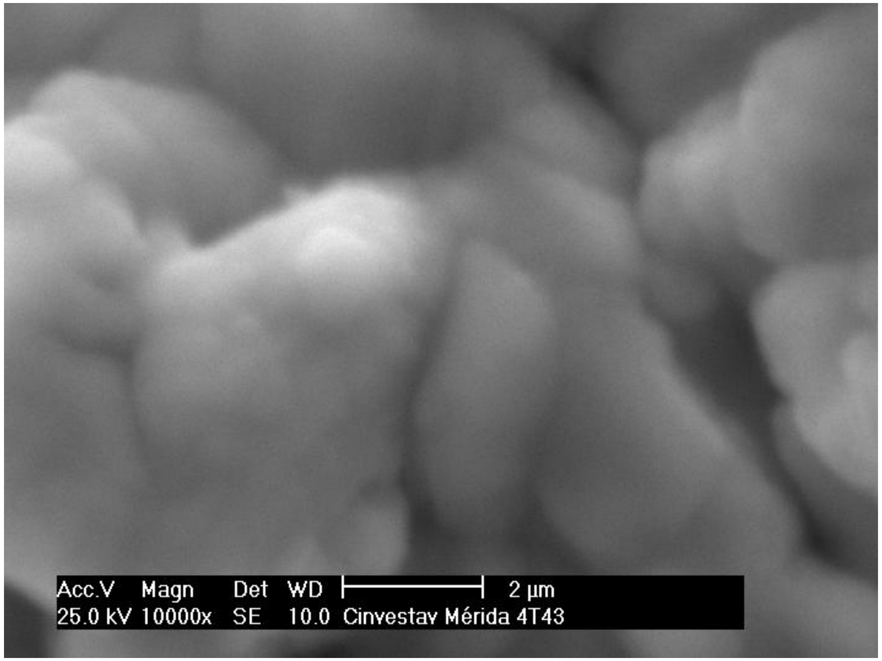


SEM image

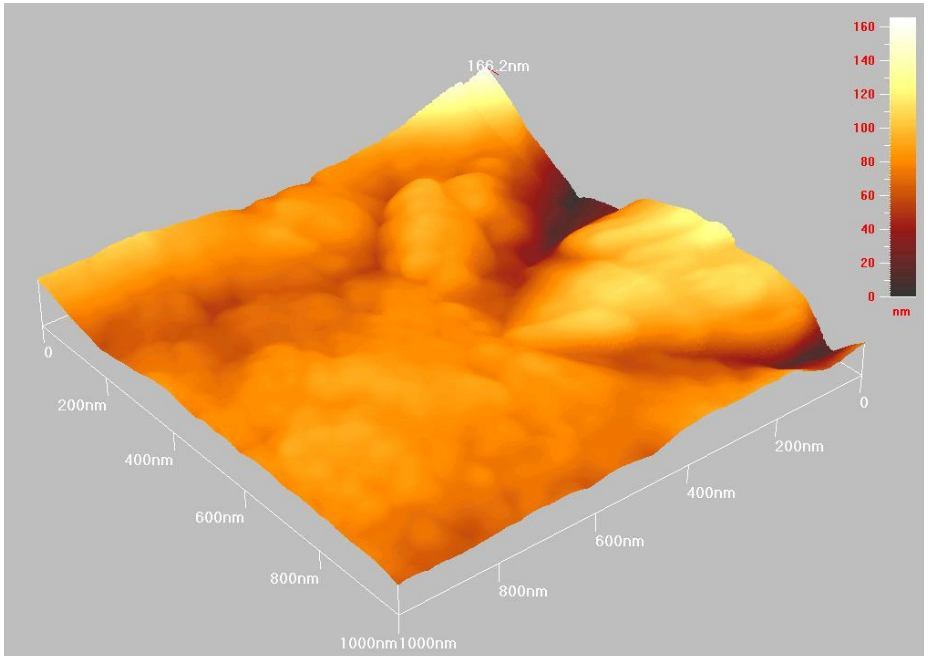
- Cu/Mo as a back contact.
- Good grain size and few holes.
- We can see grains that coalesced .

Details of the Mo/Cu/CdTe surface

SEM image



AFM image



- **The grain CdTe has roughness.**
- **The series resistance depend of how the Mo contact is deposited**
- **Then, the series resistance also depend on CdTe surface.**

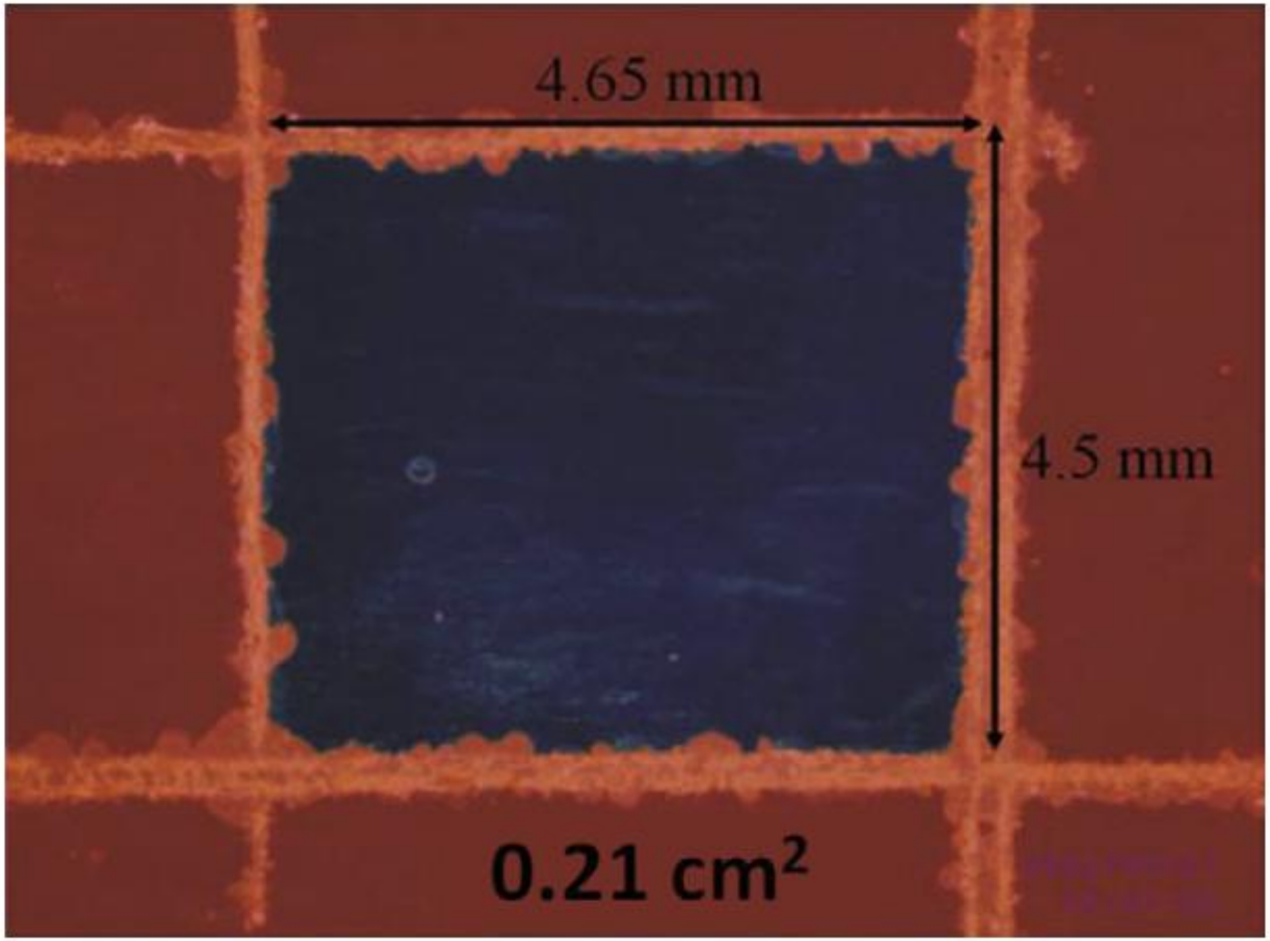


Fig. 2. Picture from digital microscope Model 111619172 of Labtronic Scientific with a zoom of 7X. The dark area selected for the Corel Photopaint is the real cell area and include the irregularities.

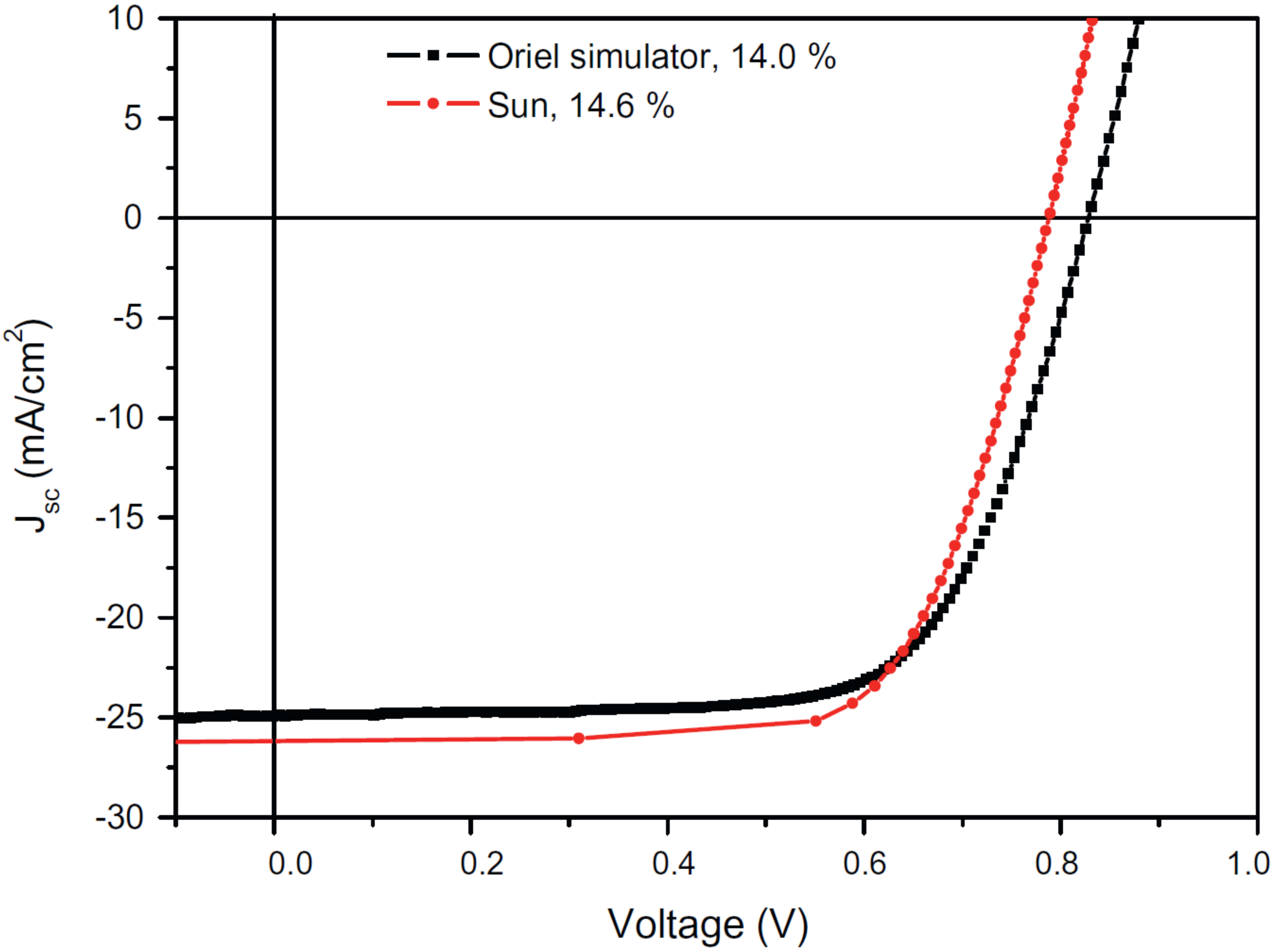


Fig. 5. *J–V* curve for a 0.21 cm^2 illuminated CdS/CdTe solar cell.

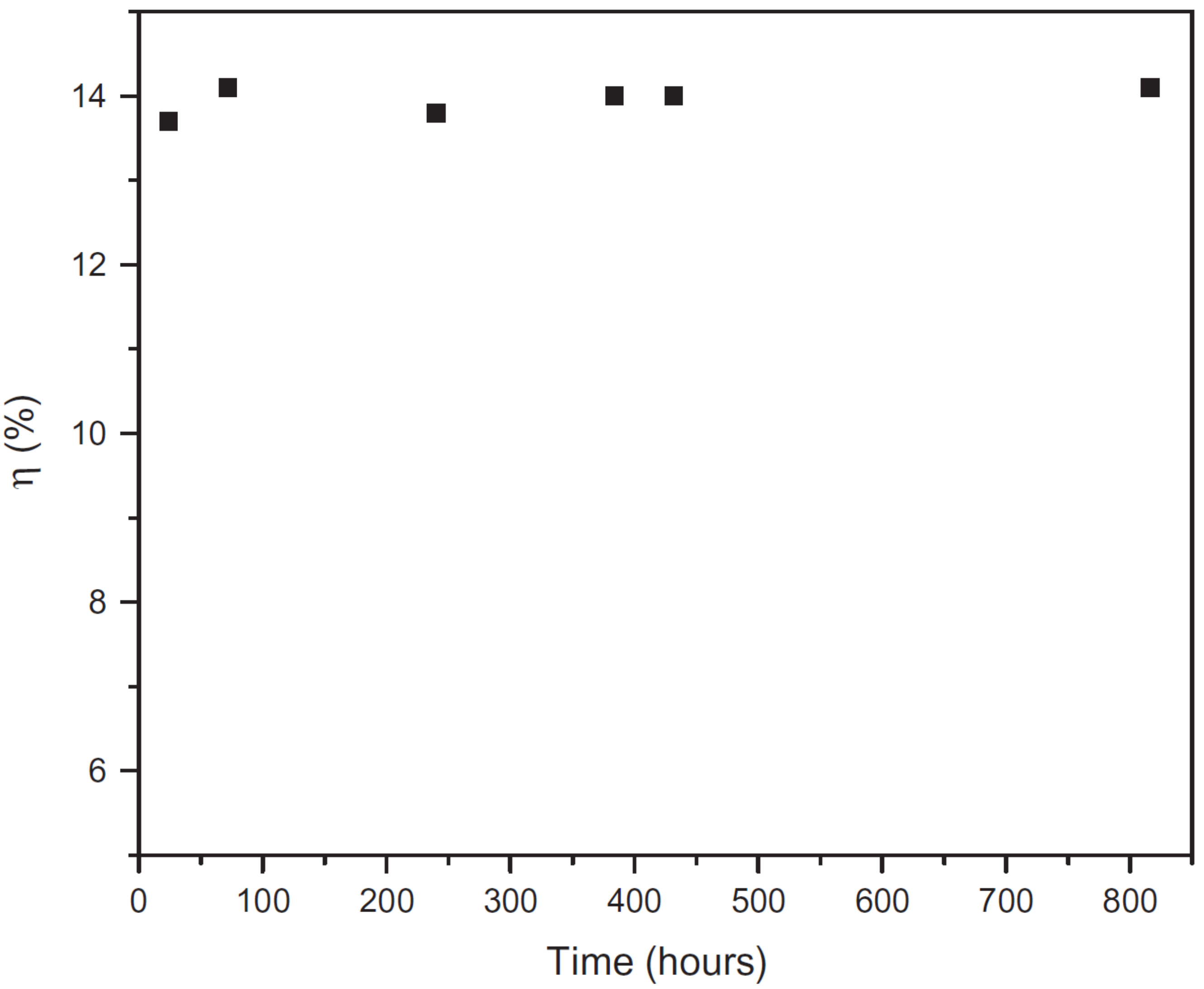
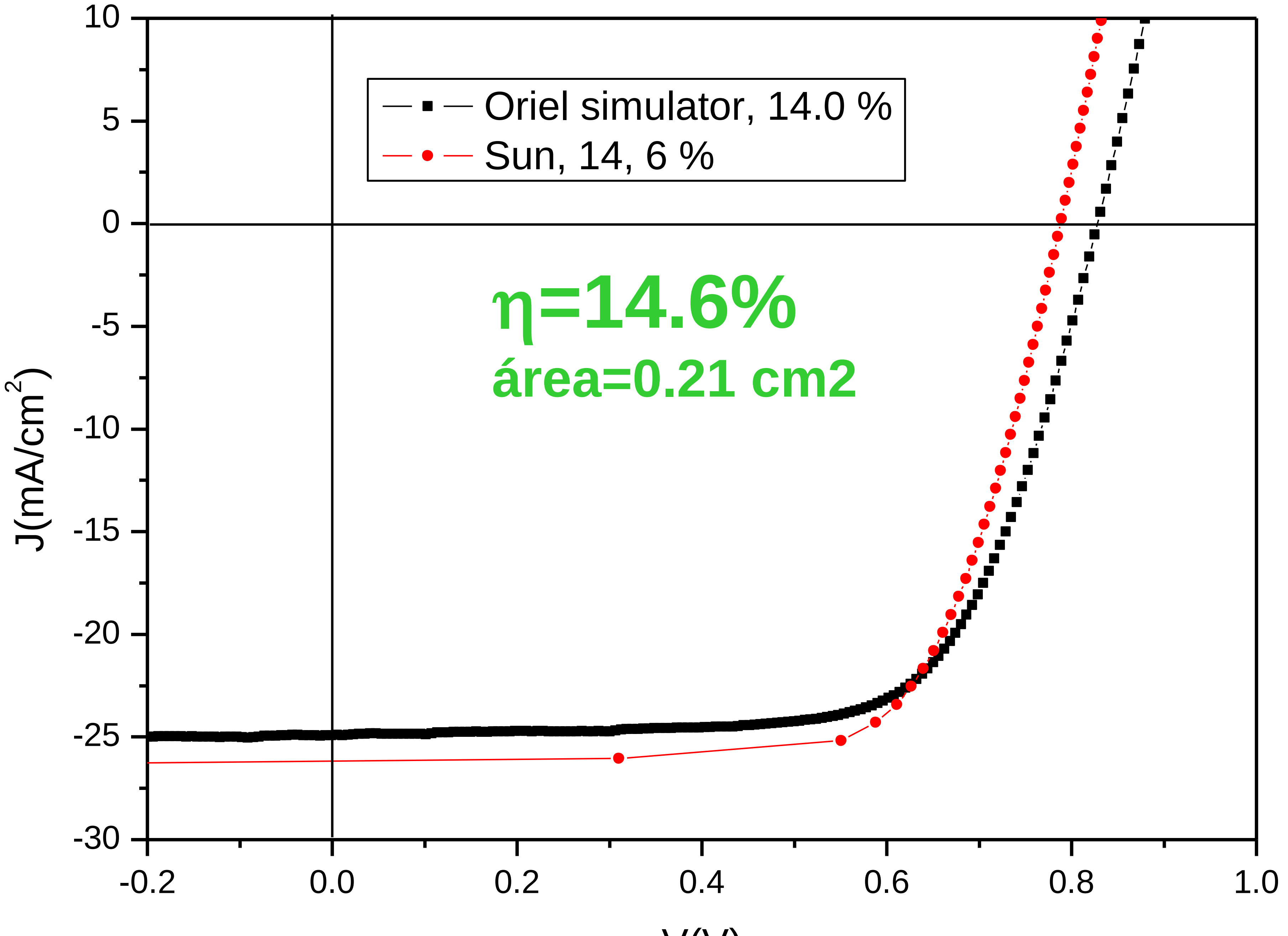


Fig. 7. Efficiency solar cell vs. time.



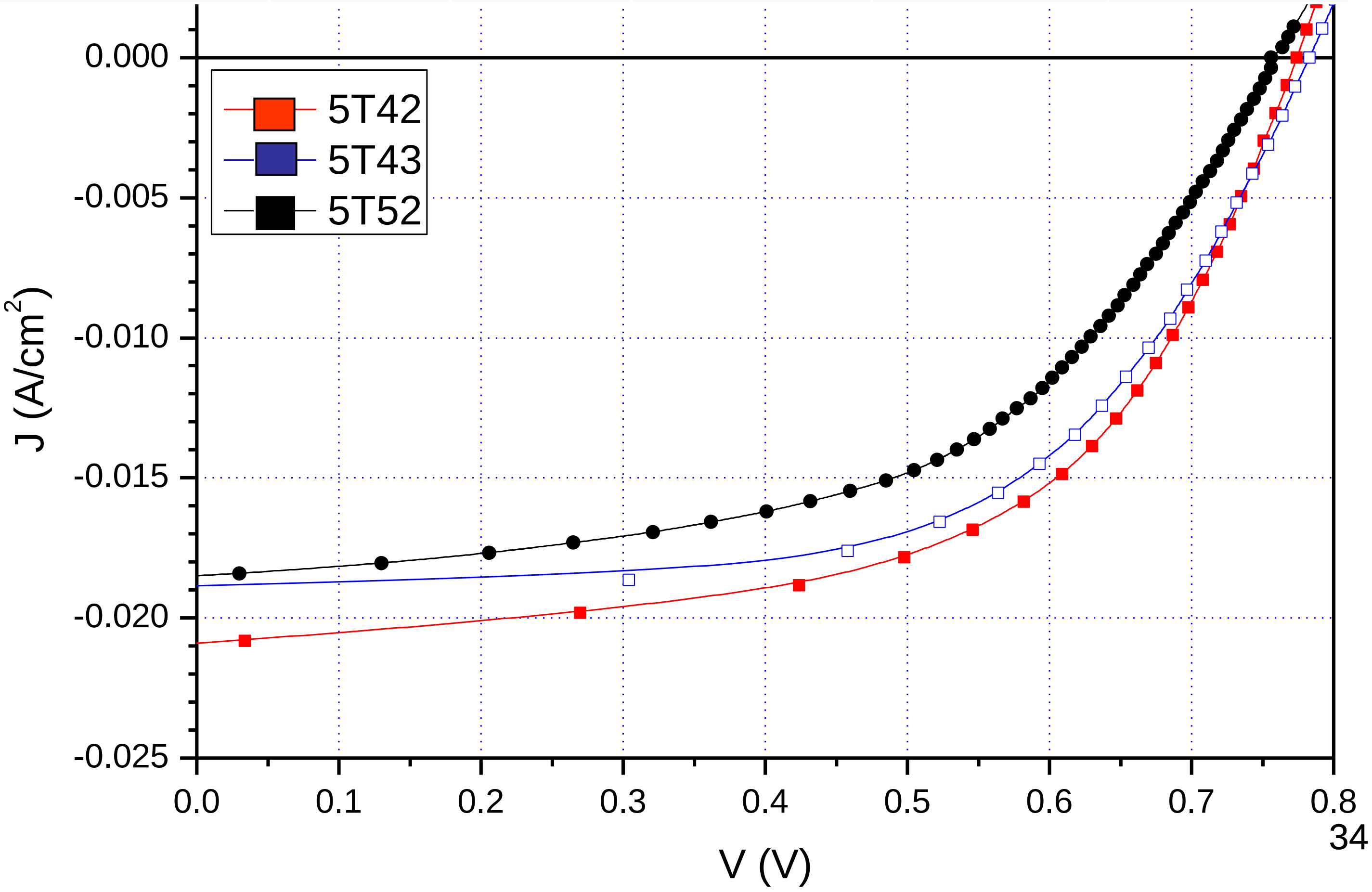
η=14.6%

área=0.21 cm2

Eficiencias obtenidas
en
celdas solares de áreas mayores
(~1 cm^2)

Name	Area (cm2)	I (mA)	J (mA/cm2)	Voc (V)	FF (%)	Rs (Ω-cm2)	Rsh (Ω-cm2)	η (%)
🟥 5T42	1.0089	21.3	21.1	0.775	56.7	7.4	278.0	10.6
🟦 5T43	0.9658	18.5	19.2	0.772	57.0	9.9	492.0	9.4
⬛ 5T52	2.71	52.2	19.23	0.745	52.4	10.8	304.0	7.5

Solar cells: $1\ cm^2$ vs $2.71\ cm^2$



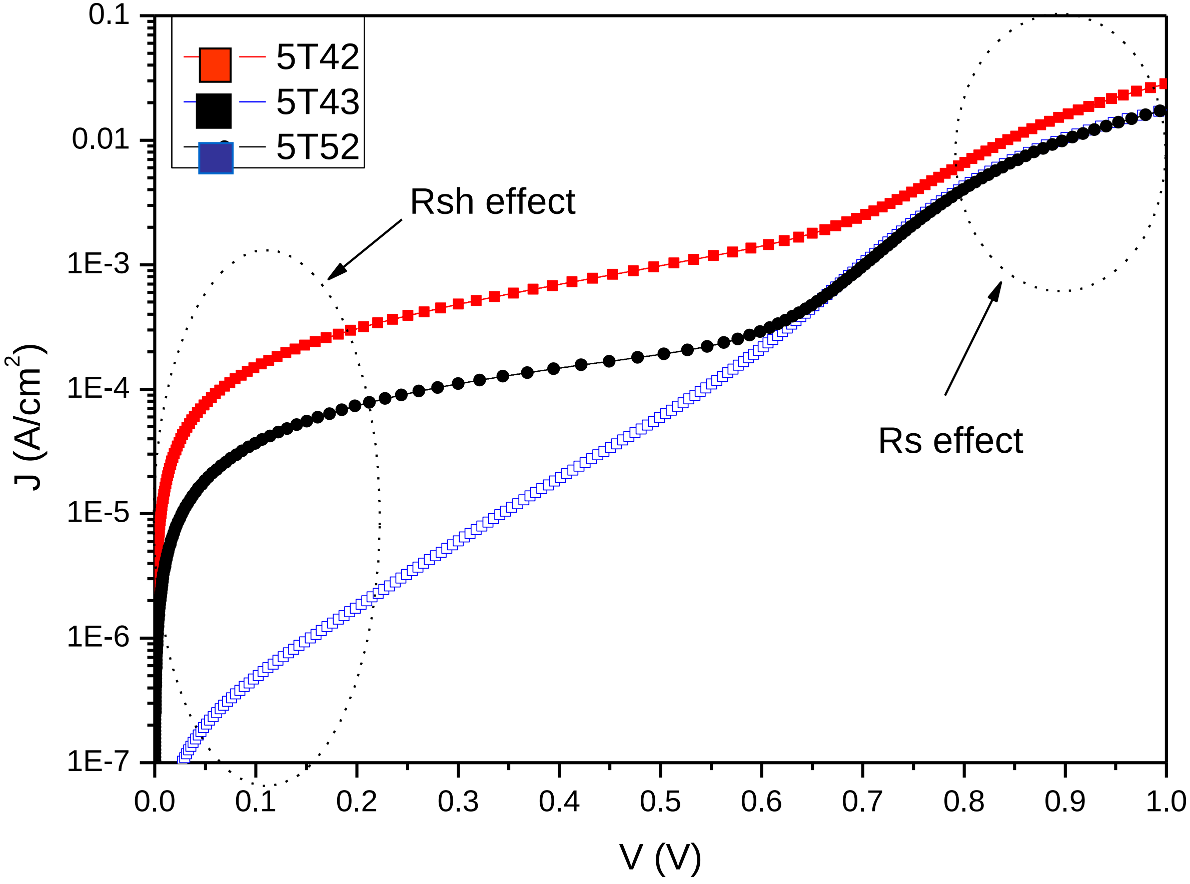
- **We have good reproducibility in Voc and FF and electrical characteristics for areas of 2.7 and $1cm^2$**

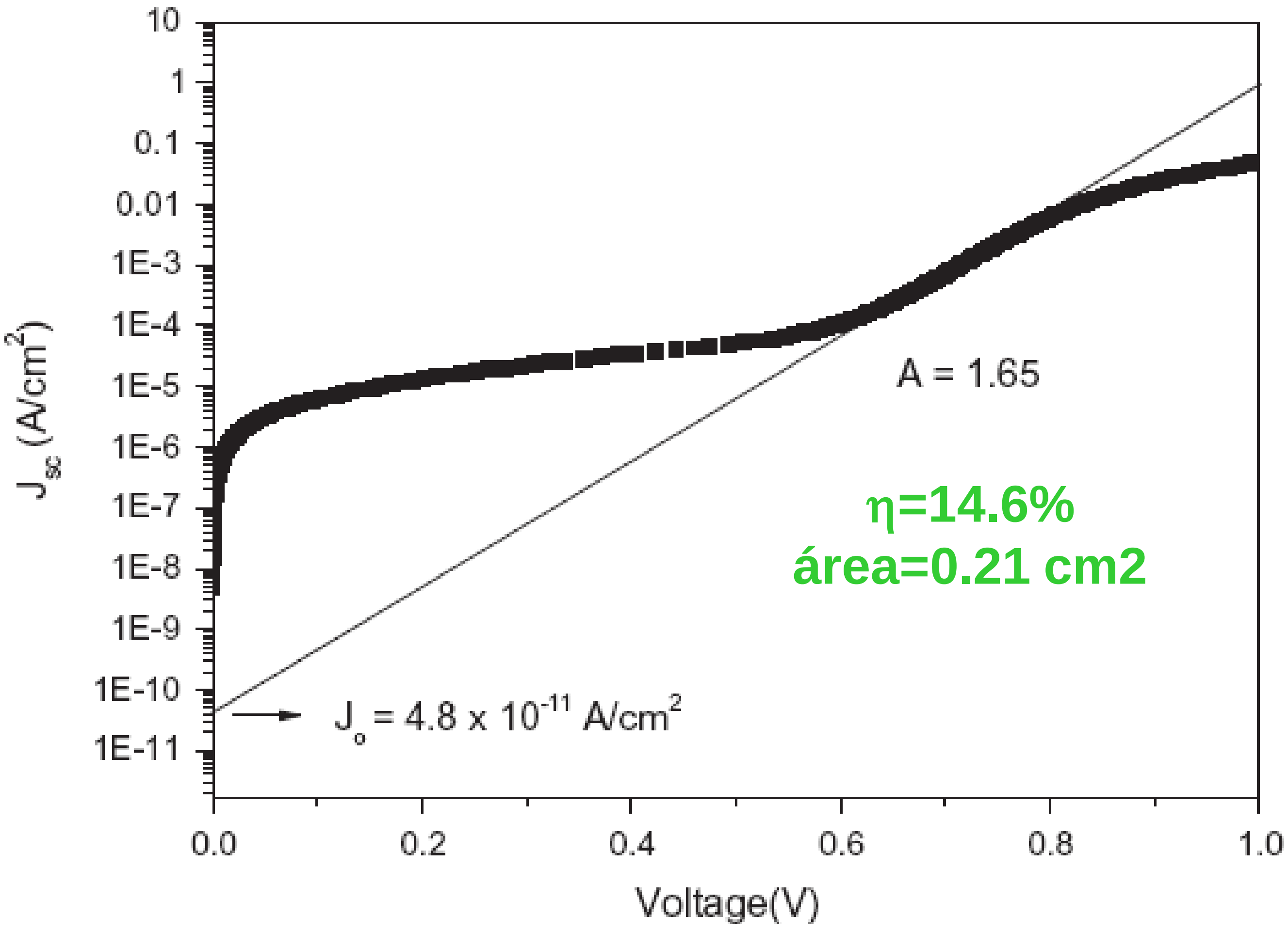
Dark J-V of CdS/CdTe solar cells

🟦 5T52 (big area) has a behavior as an ideal p-n juntion.

🟥 5T42 and ⬛ 5T43 of 1cm2 have shunting due to recombination current related with grain boundary phenomena.

- However the cells 5T42 and 5T43 are better than 5T52. It means that the shunting effect in darkness does not affect the illuminated solar cell characteristics. This phenomena is investigated.





η=14.6%
área=0.21 cm2

Fig. 6. Dark *J*–*V* curve for a 0.21 cm^2 illuminated CdS/CdTe solar cell.

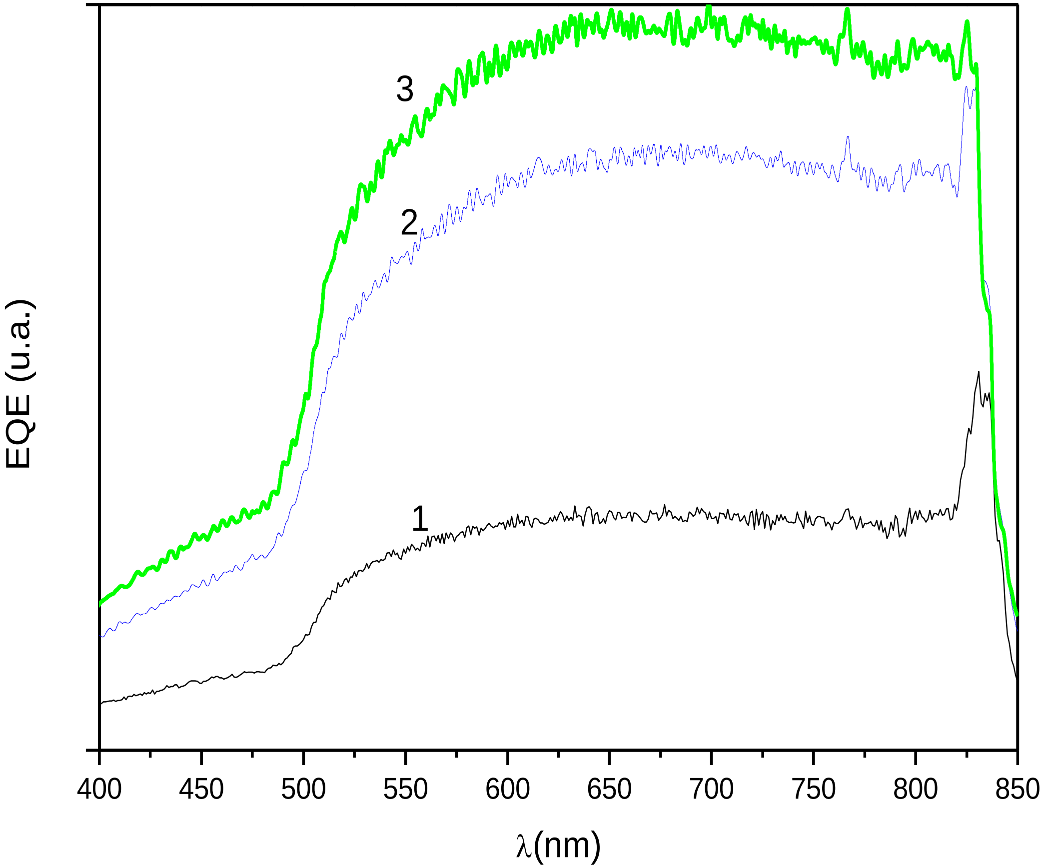
EQE of CdS/CdTe solar cell

⬛ 1 is for as born solar cell. The CdS sharpness is observed at 500-520 nm. In this case is observed a strong recombination current for wavelenghts around 825 nm.

🟦 2 After 20 minutes of light soaking the EQE spectra is changed. We can observe that EQE is improved.

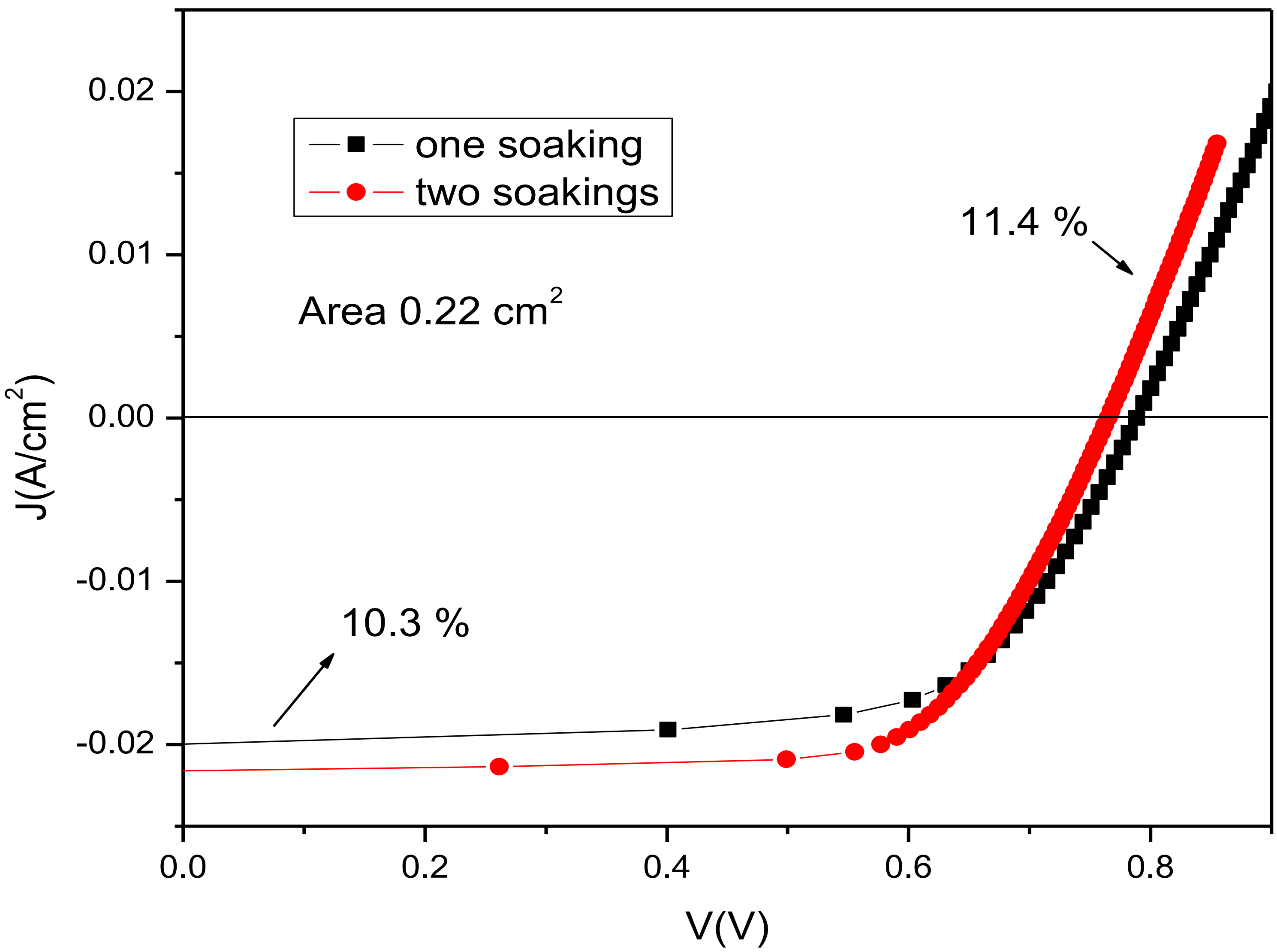
🟩 After other 20 minutes of light soaking, again the EQE spectra is improved and the recombination current is almost eliminated.

- **We concluded that in our fabrication process, the light soaking is needed.**



Typical EQE spectra obtained in our solar cells.

SOAKING



■ one soaking
● two soakings
11.4 %
Area 0.22 cm^2
10.3 %
J(A/cm^2)
0.02
0.01
0.00
-0.01
-0.02
0.0
0.2
0.4
0.6
0.8
V(V)

Colaboracion para la fabricacion de paneles y celdas solares en la Universidad de Parma y en Arendi, Italia

UNIVERSITA DEGLI STUDI DI PARMA
Facoltà di Scienze MM. FF. NN.

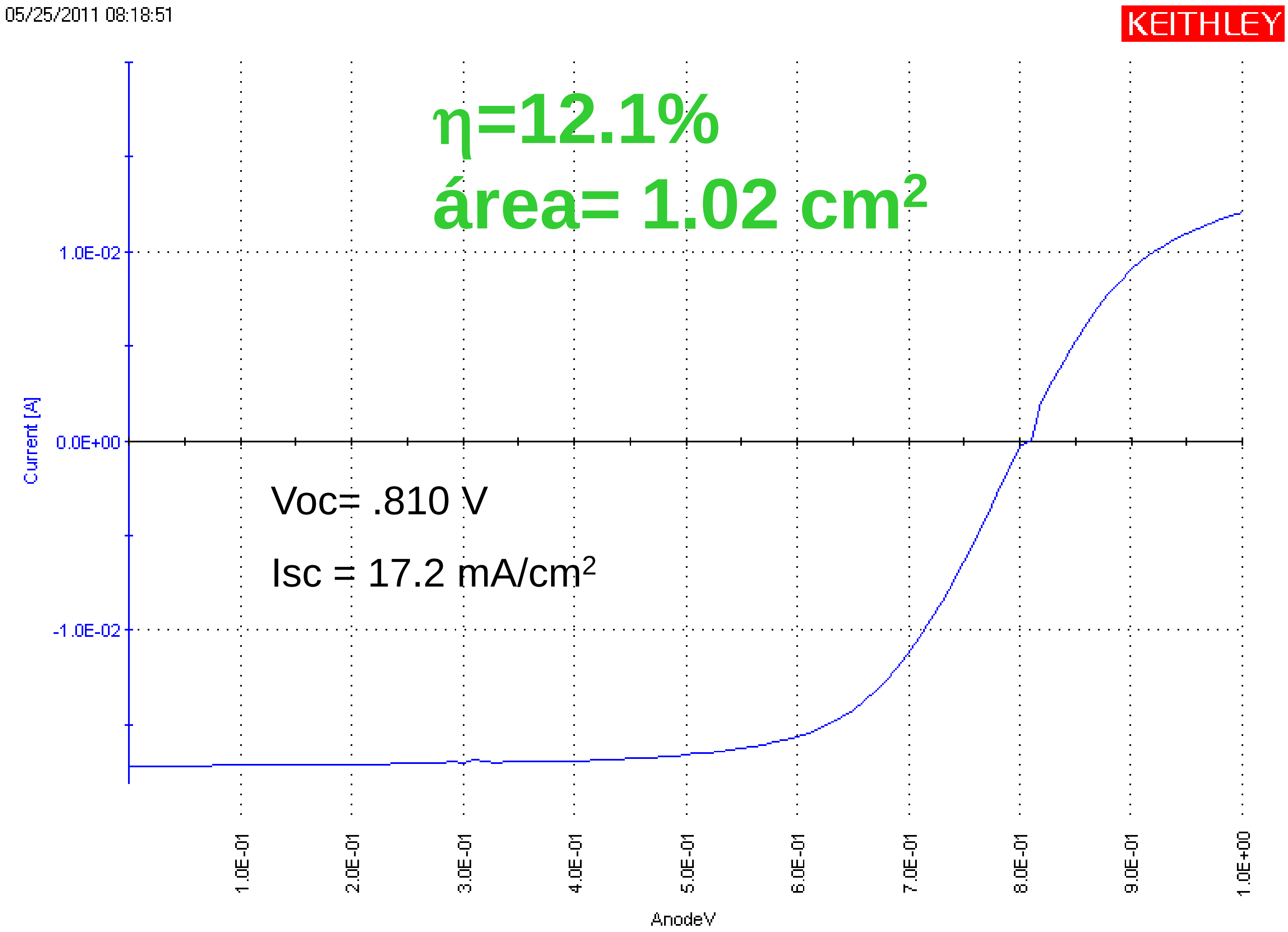
Nicola Romeo
y
Alessio Bosio
University of Parma, Italy

CINVESTAV
Unidad Mérida

Juan Luis Peña Chapa
CINVESTAV-IPN UNIDAD MERIDA

Prof. Nicola Romeo en su laboratorio mostrando el panel FV no. 9 fabricado durante la primera producción de la línea automática de la compañía italiana Arendi en Milan.

Celda solar fabricada en la Universidad de Parma



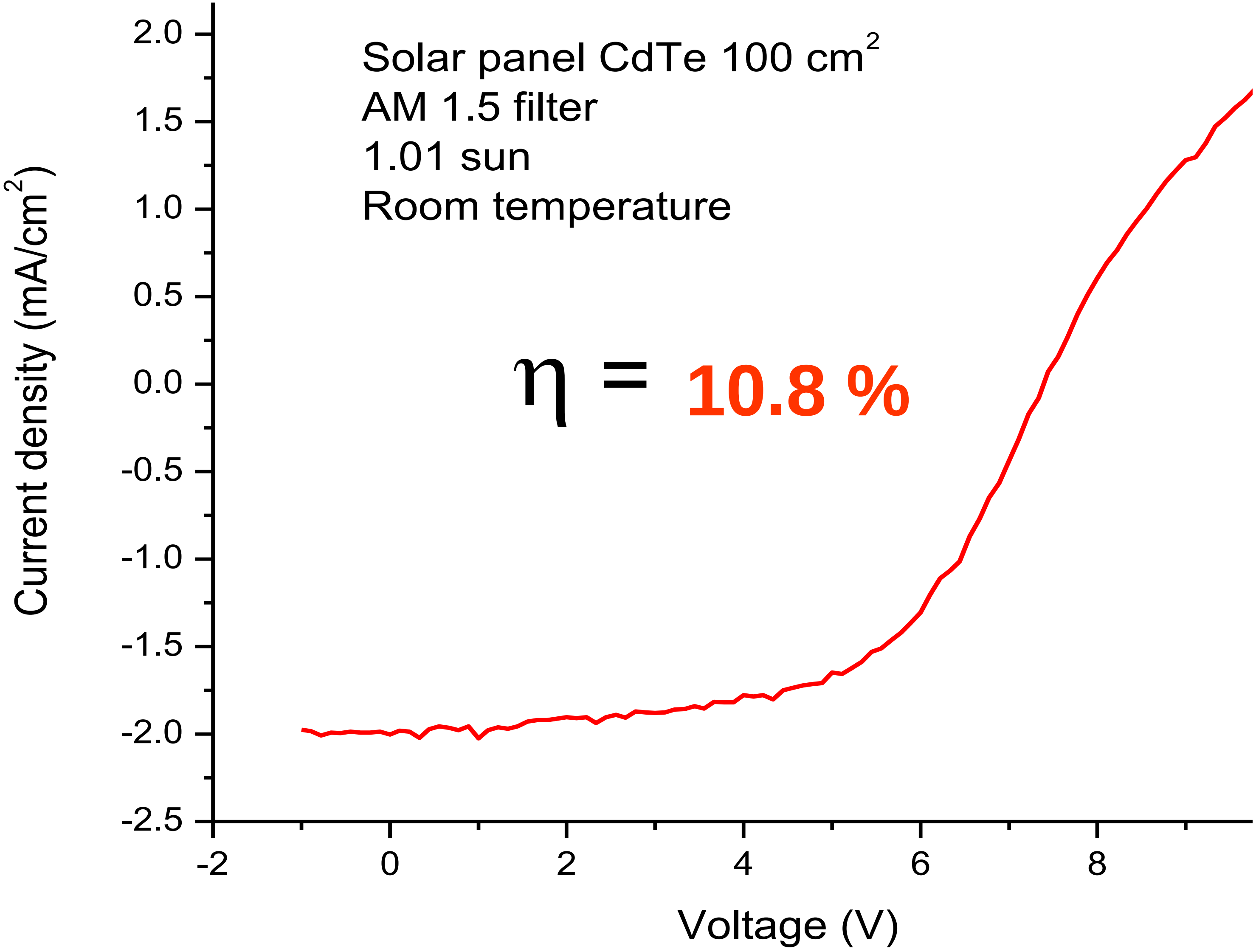
η=12.1%

área= 1.02 cm^2

Voc= .810 V

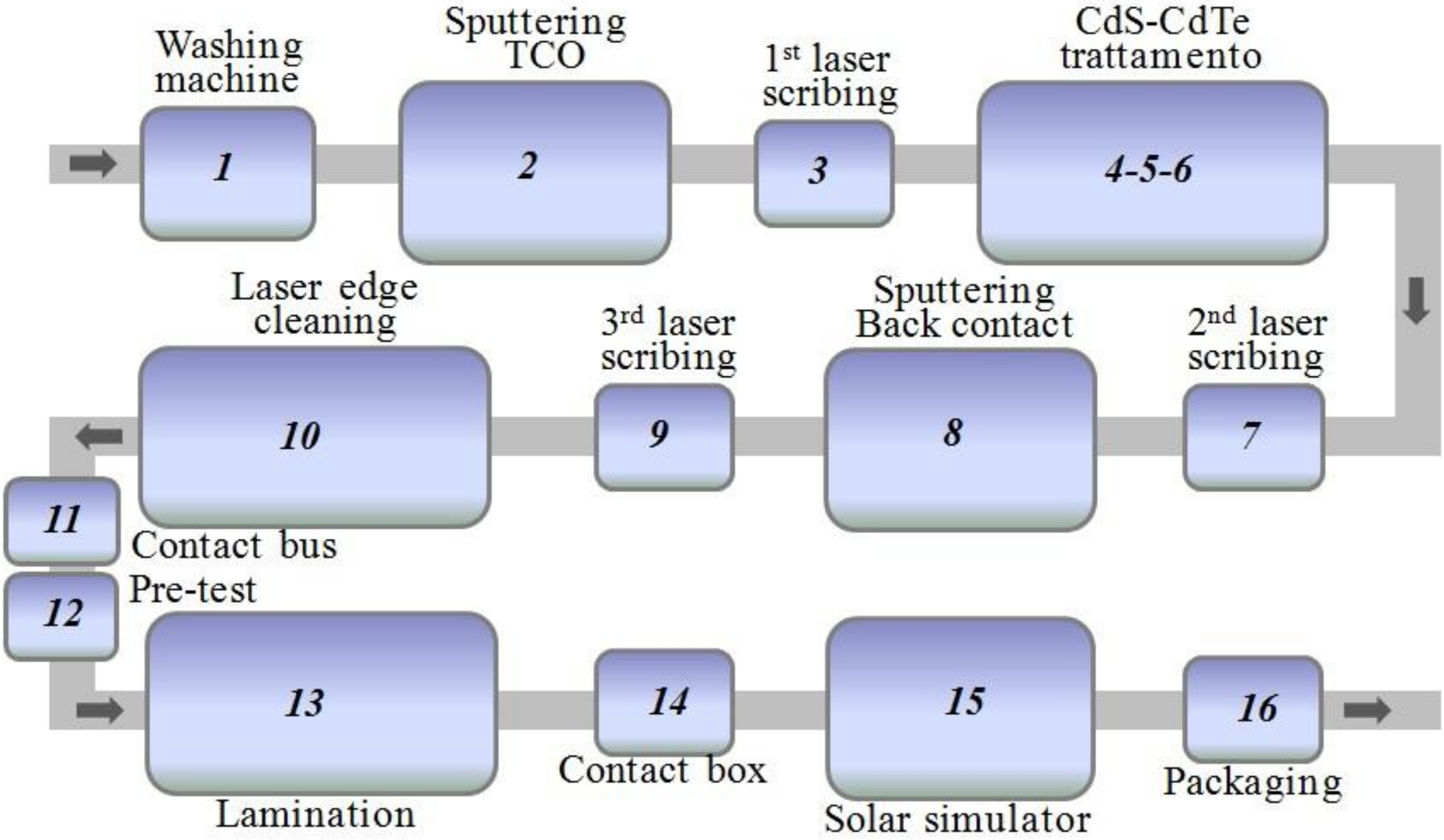
Isc = 17.2 mA/cm^2

Panel de 100 cm² fabricado en la Universidad de Parma y Arendi, Italia

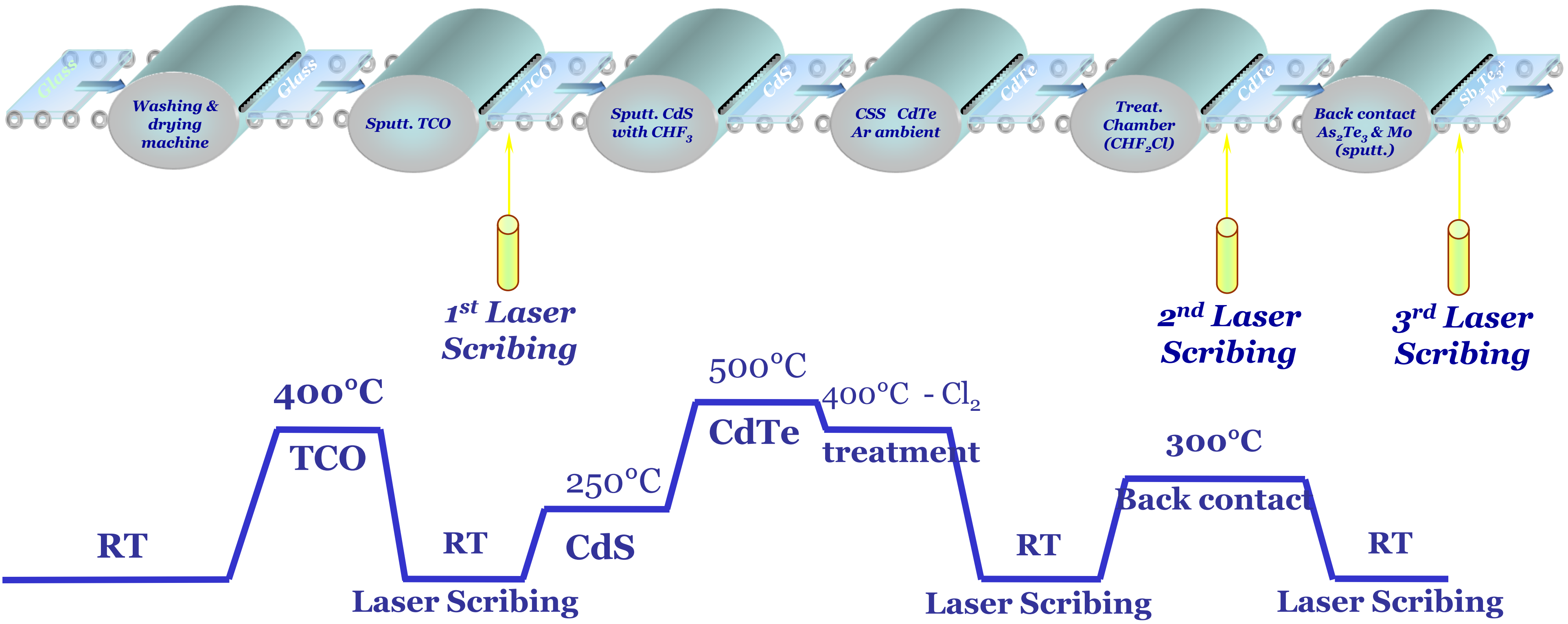


The industrial process

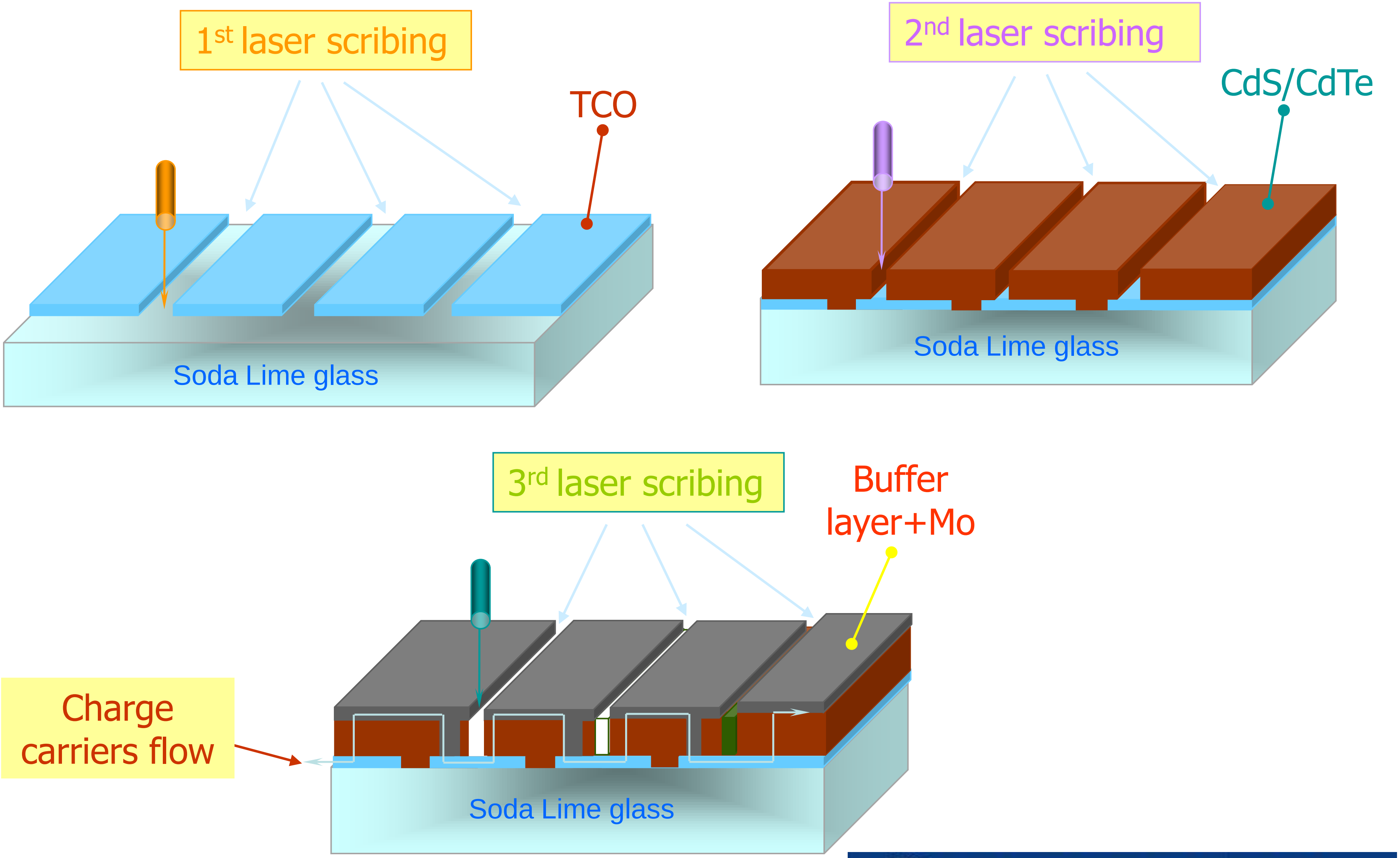
The industrial process



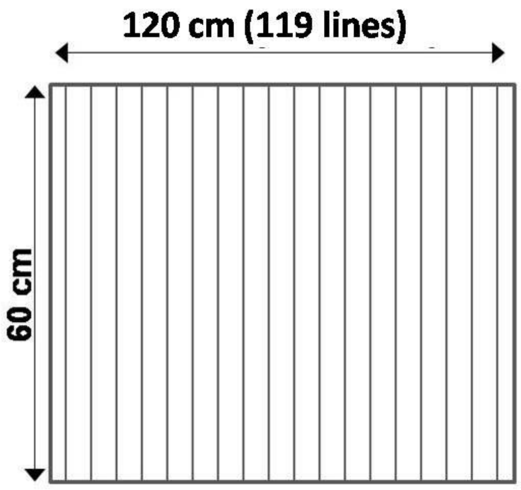
The industrial process



The laser scribing



Production Line: Laser scribing



Module:
parallel lines
1cm distant one
from each other.

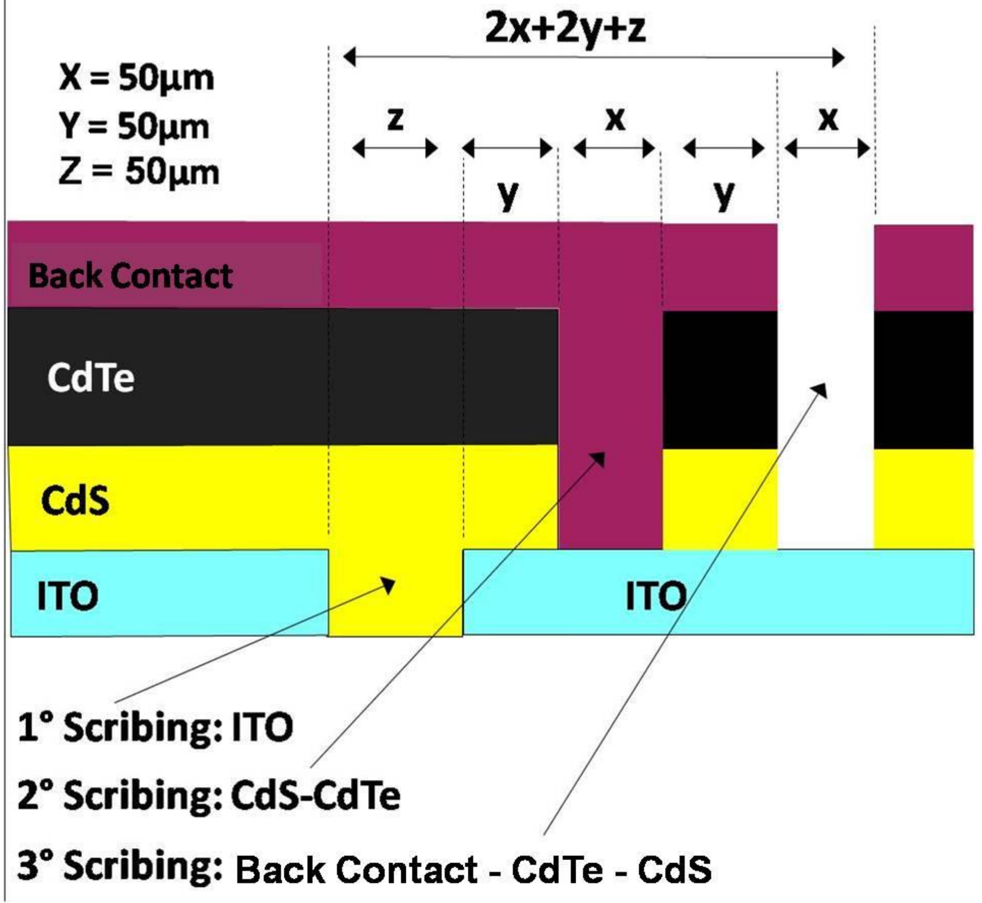


Foto de la linea de CSS en Arendi

Foto de la linea de deposito del contacto metalico en Arendi

The better performance in our CdTe/CdS solar cell is due to:

1. **The utilization of ZnO buffer layer.**
2. **The CdS grown by RF sputtering.**
3. **The chlorination with $CHClF_2$ (chlorodifluoromethane) gas mixed with other gases.**
4. **The back contact deposited by sputtered bilayer of Cu/Mo.**

Conclusions

- **The methodology allows repeatable solar cells.**
- **As born solar cell needs light soaking for improving.**
- **The technology can be used to fabricate CdS/CdTe thin film solar cells of high efficiency**

¡GRACIAS¡

¿PREGUNTAS?

Dzibilchaltún
Mérida, Yucatán

Póster 277 Friday

Optimizing the growth parameters of ITO for application in solar cells CdS/CdTe

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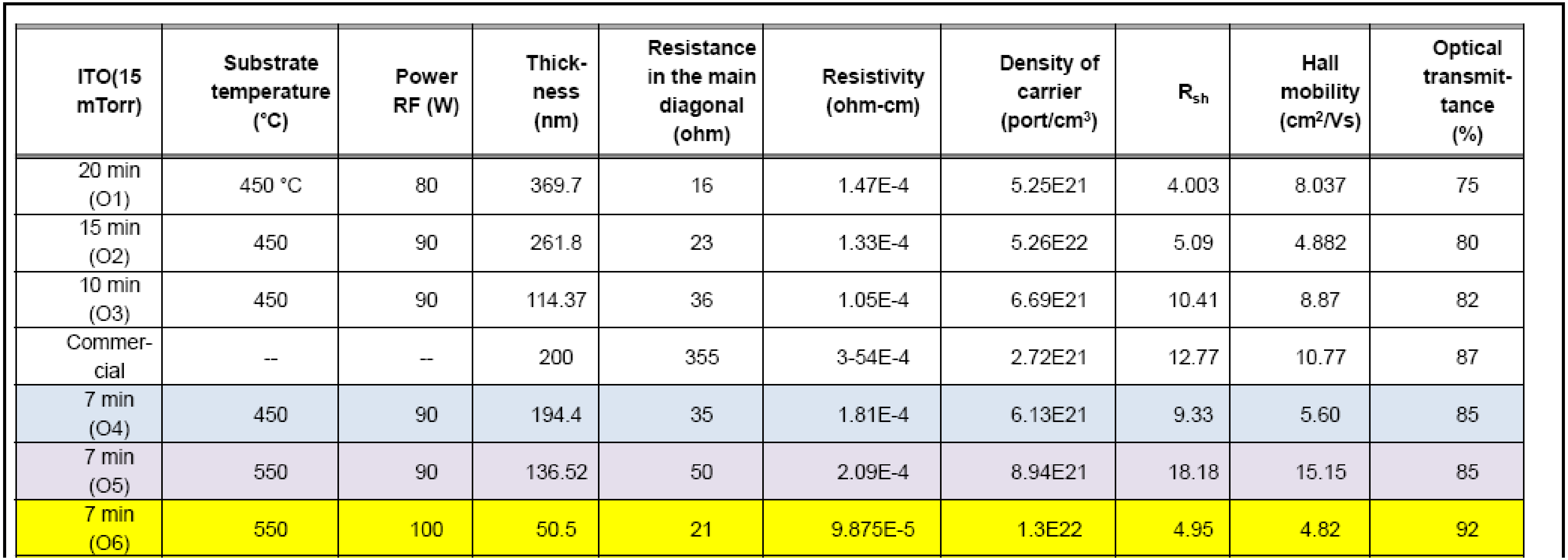

ITO(15 mTorr)	Substrate temperature (°C)	Power RF (W)	Thick-ness (nm)	Resistance in the main diagonal (ohm)	Resistivity (ohm-cm)	Density of carrier (port/cm^3)	R_{sh}	Hall mobility (cm^2/Vs)	Optical transmit-tance (%)
20 min (O1)	450 °C	80	369.7	16	1.47E-4	5.25E21	4.003	8.037	75
15 min (O2)	450	90	261.8	23	1.33E-4	5.26E22	5.09	4.882	80
10 min (O3)	450	90	114.37	36	1.05E-4	6.69E21	10.41	8.87	82
Commer-cial	--	--	200	355	3-54E-4	2.72E21	12.77	10.77	87
7 min (O4)	450	90	194.4	35	1.81E-4	6.13E21	9.33	5.60	85
7 min (O5)	550	90	136.52	50	2.09E-4	8.94E21	18.18	15.15	85
7 min (O6)	550	100	50.5	21	9.875E-5	1.3E22	4.95	4.82	92