

A. PARRETTA

CORSO DI OTTICA APPLICATA

A.A. 2011-2012

RIFLETTOMETRO PROM



**22nd European Photovoltaic Solar Energy Conference and Exhibition**

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**3-7 Settembre 2007, Fiera di Milano**

# MULTI-SOURCE PULSED REFLECTOMETER FOR FAST OPTICAL MAPPING OF A PV MODULE

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&

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## **PURPOSE:**

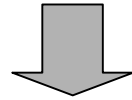
To study the optical properties of PV modules by measuring the optical losses by reflection

To evaluate the energetic loss (one of five) associated to these optical losses

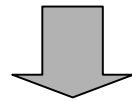
To set up program codes which simulate the real operating conditions of PV modules (outdoors)

# “ENERGETIC LOSS” MECHANISMS

$\eta_{\text{STC}}$



- 1) Reflection losses  
(polarized light)
- 2) Reflection losses  
(non normal incidence)
- 3) Spectral effects
- 4) Low irradiance level losses
- 5) Temperature effects

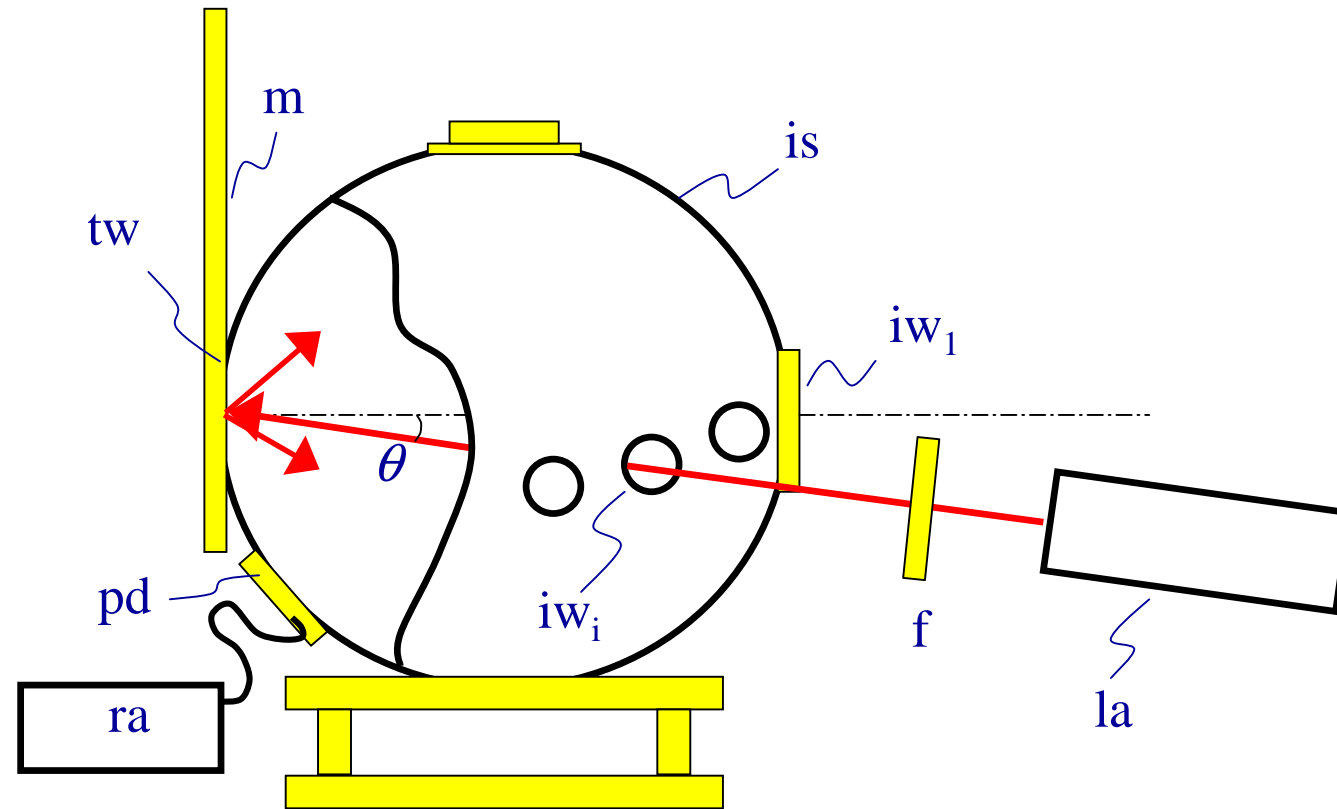


$\eta_{\text{RRC}}$

Real Reporting Conditions (RRC)

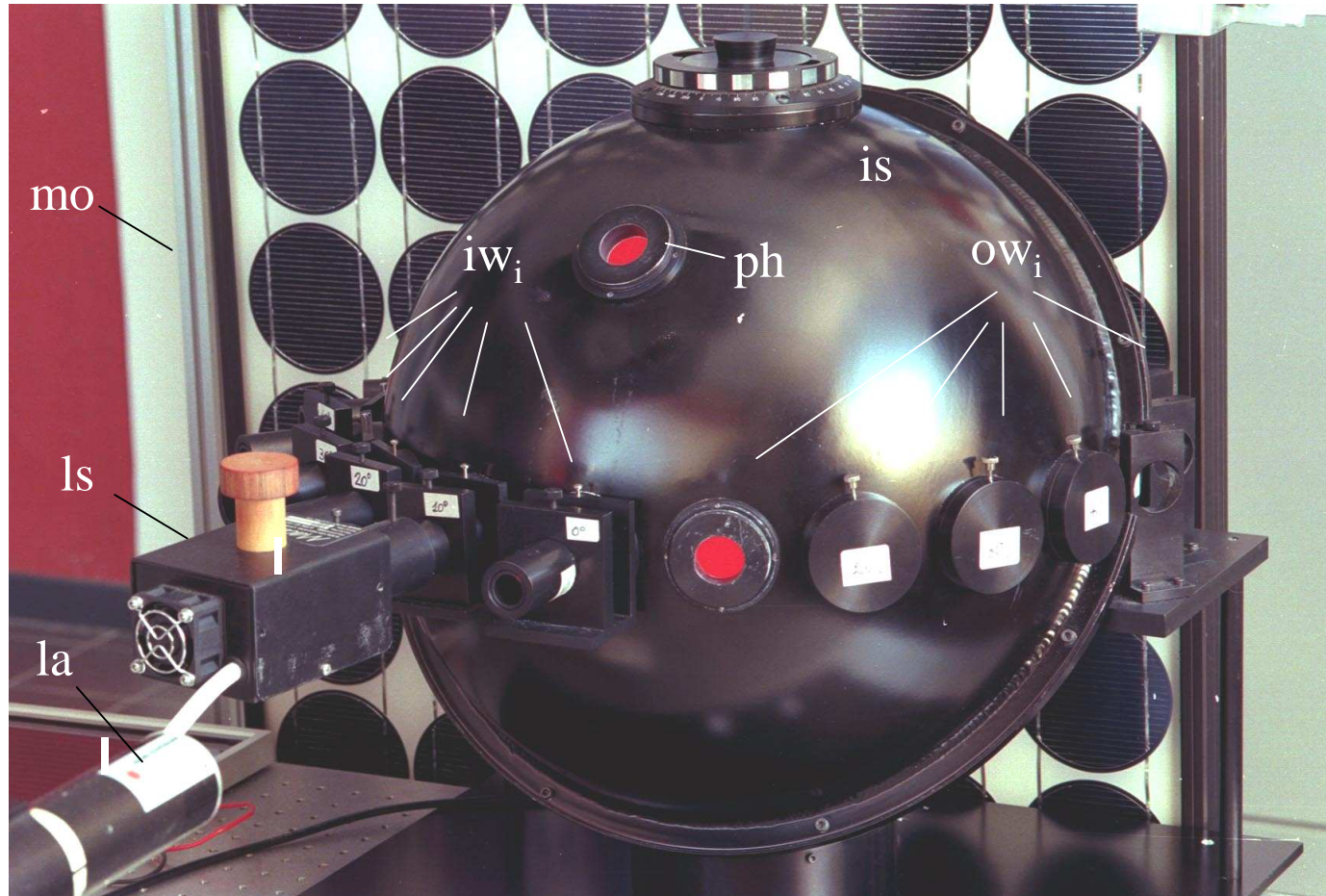
# “ROSE” REFLECTOMETER

(Reflectometer for Optical Measurements in Solar Energy)



Basic principle

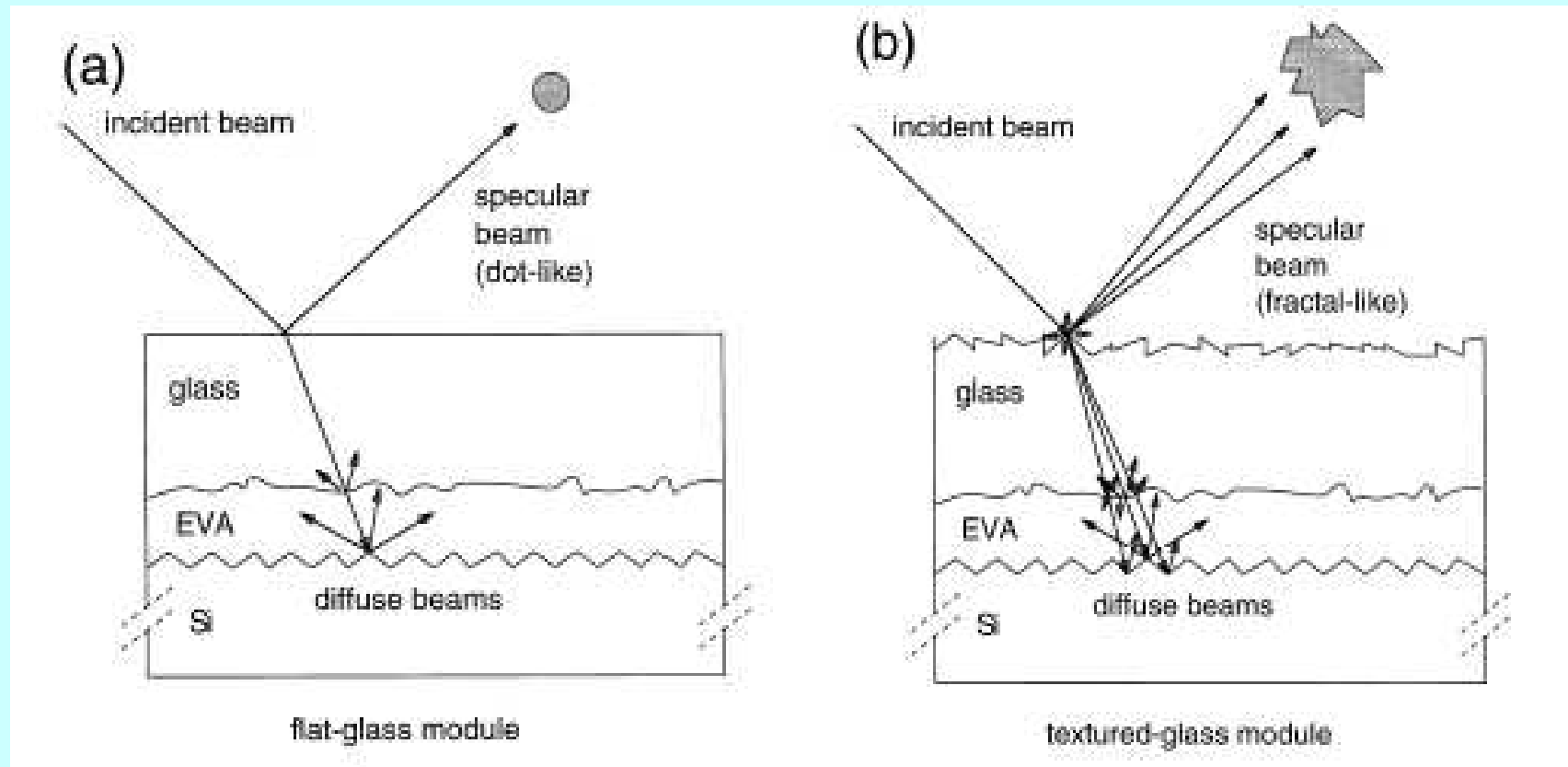
# “ROSE” REFLECTOMETER



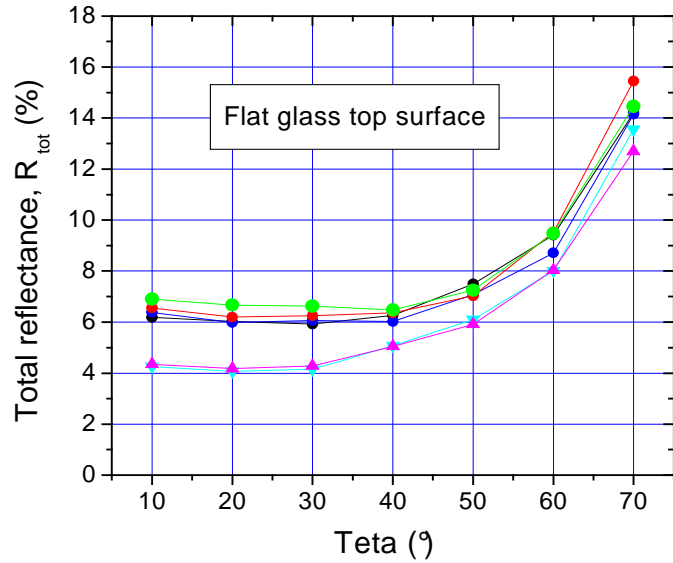
ROSE reflectometer applied to measurement of  $R$  vs.  $\theta$  of  $c$ -Si modules.

*A. Parretta, Italian Patent., Application N. RM 97 A 000676, 5 November 1997.*

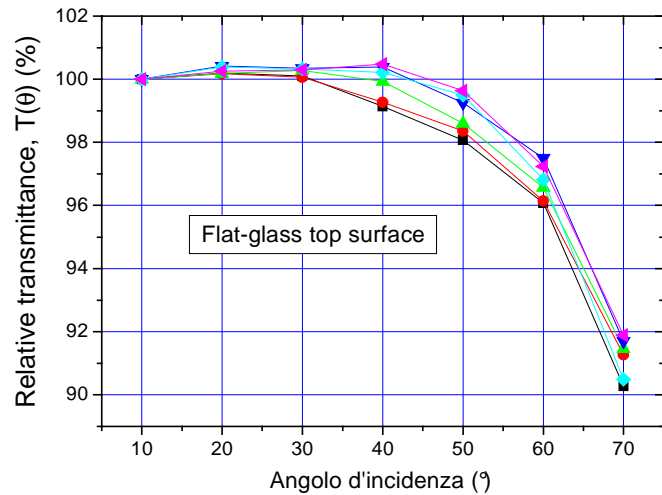
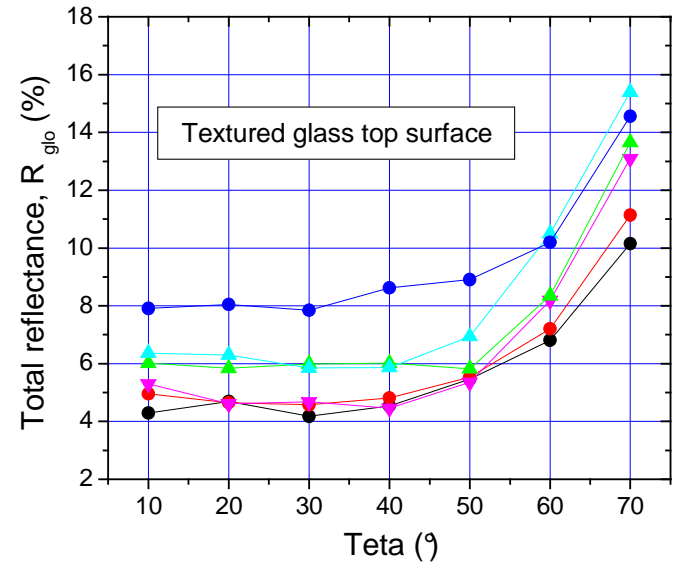
# OPTICAL REFLECTANCE



# OPTICAL REFLECTANCE AND TRANSMITTANCE

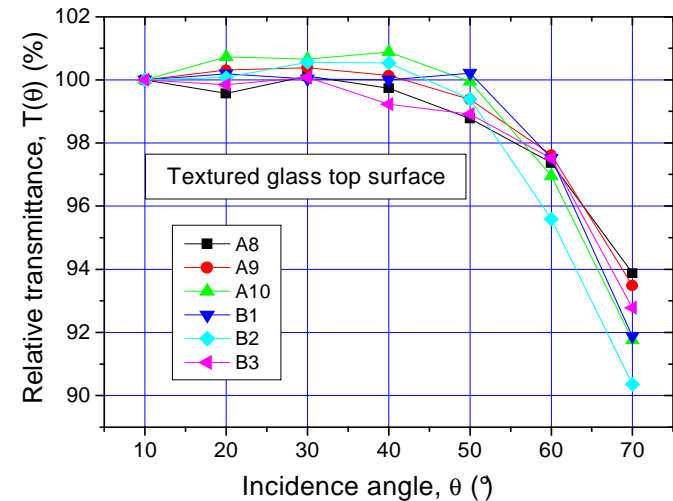
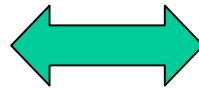


$R(\vartheta)$



$\tau(\vartheta) = \dots$

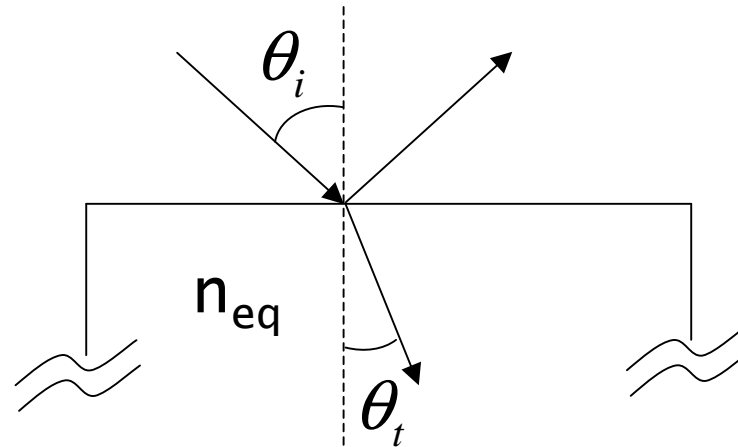
$$= \frac{T(\vartheta)}{T(0)} = \frac{1 - R(\vartheta)}{1 - R(0)}$$





# OPTICAL LOSSES

Module =



$$T(\theta) = 1 - R(\theta) = 0.5 n_{eq} (\cos \theta_t / \cos \theta_i) (\tau_p^2 + \tau_s^2)$$

$$\tau_p = (2 \sin \theta_t \cos \theta_i) / [\sin(\theta_i + \theta_t) \cos(\theta_i - \theta_t)]$$

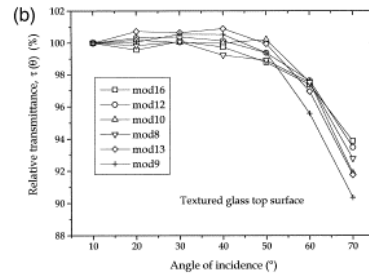
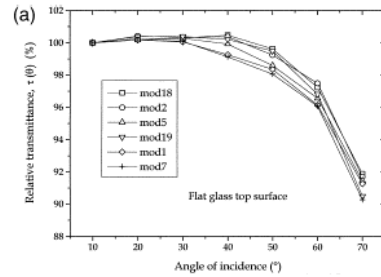
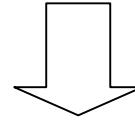
$$\tau_s = (2 \sin \theta_t \cos \theta_i) / \sin(\theta_i + \theta_t)$$

$$\sin \theta_t = \sin \theta_i / n_{eq}$$

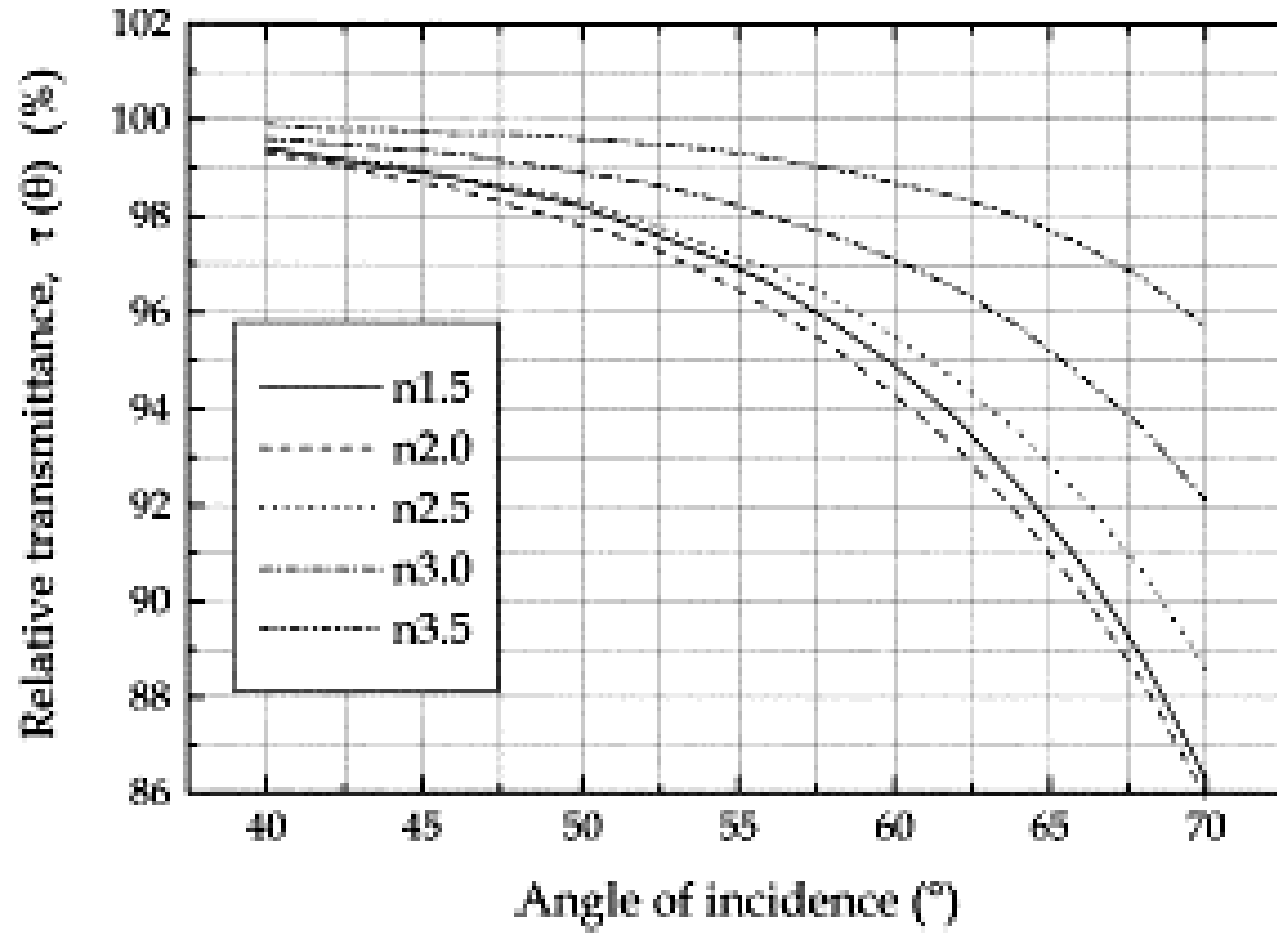
Performance ratio for reflection loss:

$$PR_R = T(\theta) / T(0)$$

# SIMULATED RELATIVE TRANSMITTANCE



↑  
exp. curves



## EQUIVALENT REFRACTIVE INDEX

<b>Category</b>	<b>Front structure</b>	<b><math>n_{eq}</math></b>
A	Flat-glass; text-Si	3.0
B	Flat-glass; ARC; text-Si	2.5
C	Flat-glass; ARC; flat-Si	2.5
D	Text-glass; text-Si	3.0
E	Text-glass; ARC; flat-Si	3.0
F	Text-glass; ARC; text-Si	3.0

**PROM APPARATUS**  
(Pulsed Reflectometer for Optical Mapping)

*What is it for?*

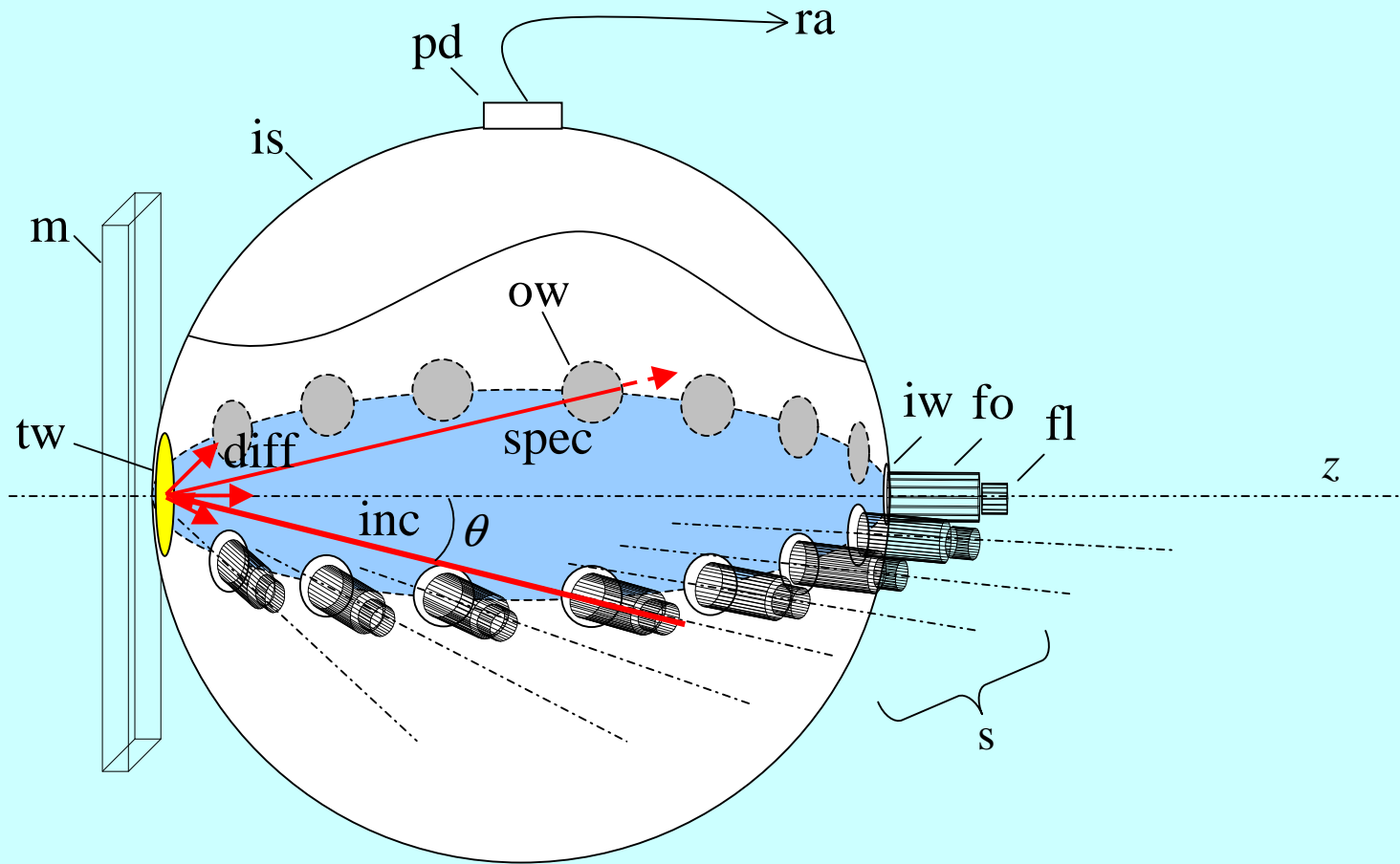
Total and diffuse reflectance measurements  
on large-area samples

Fast optical mapping of photovoltaic modules

Optical and electrical maps on integrated modules

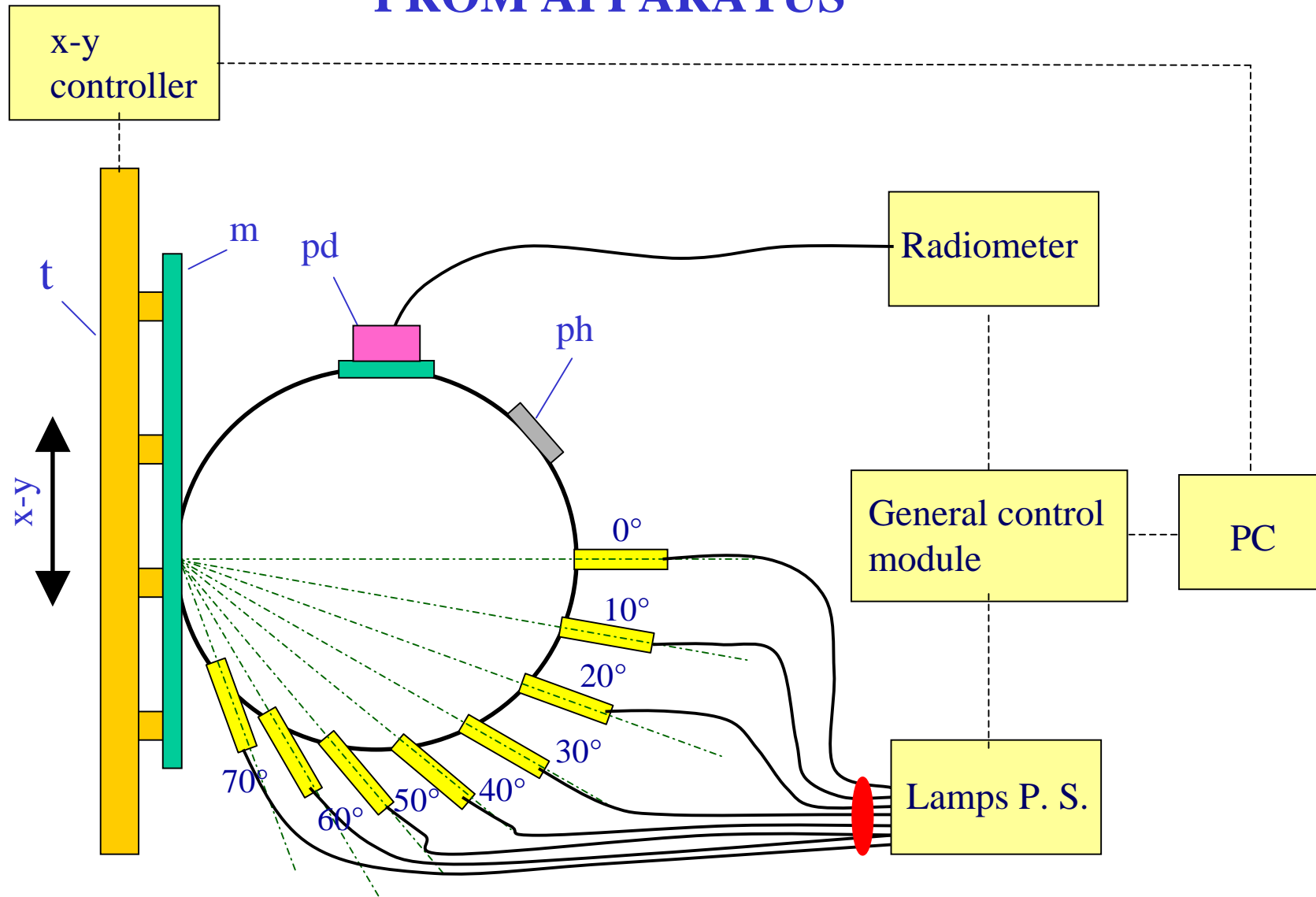


# PROM APPARATUS



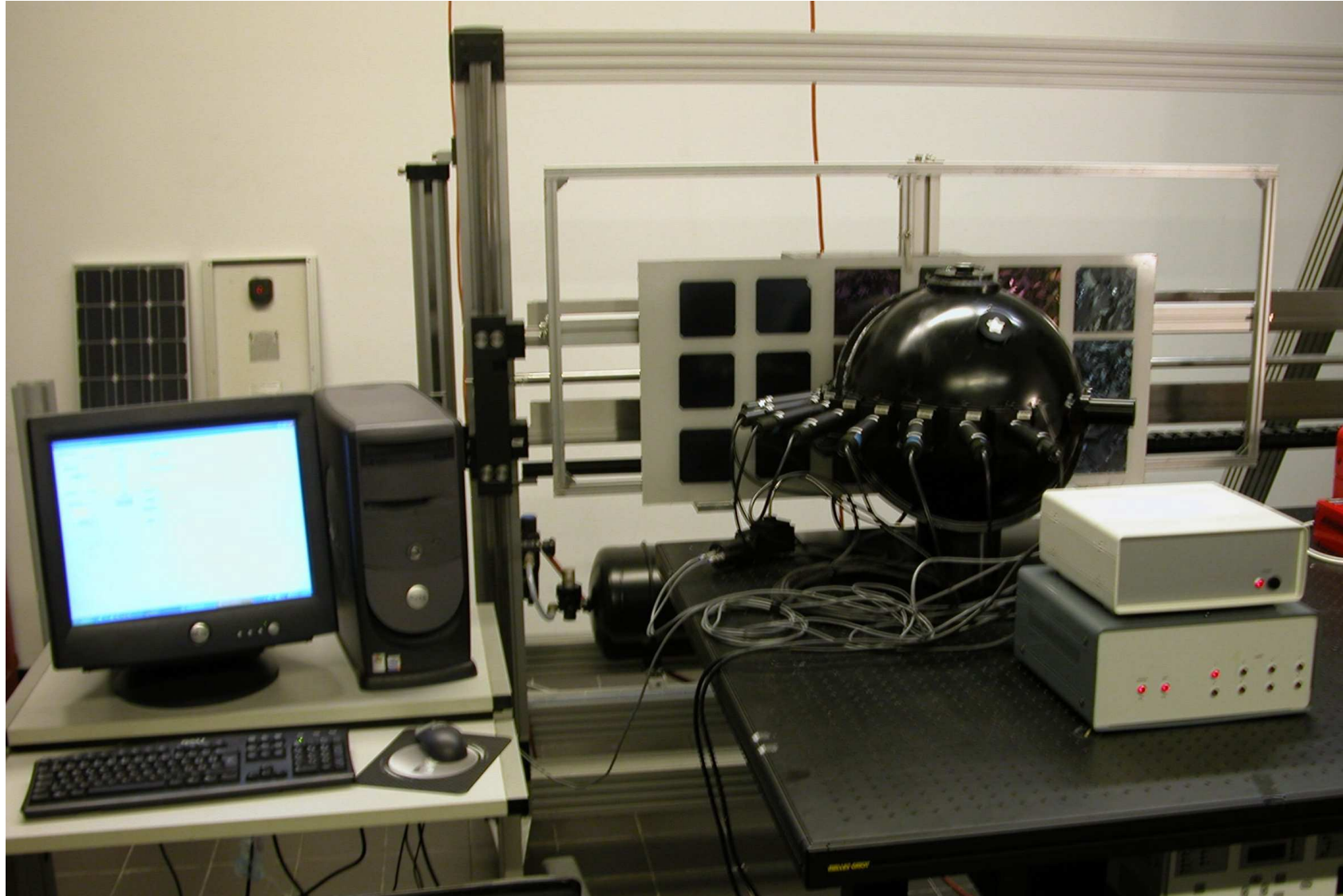
Basic principle

# PROM APPARATUS

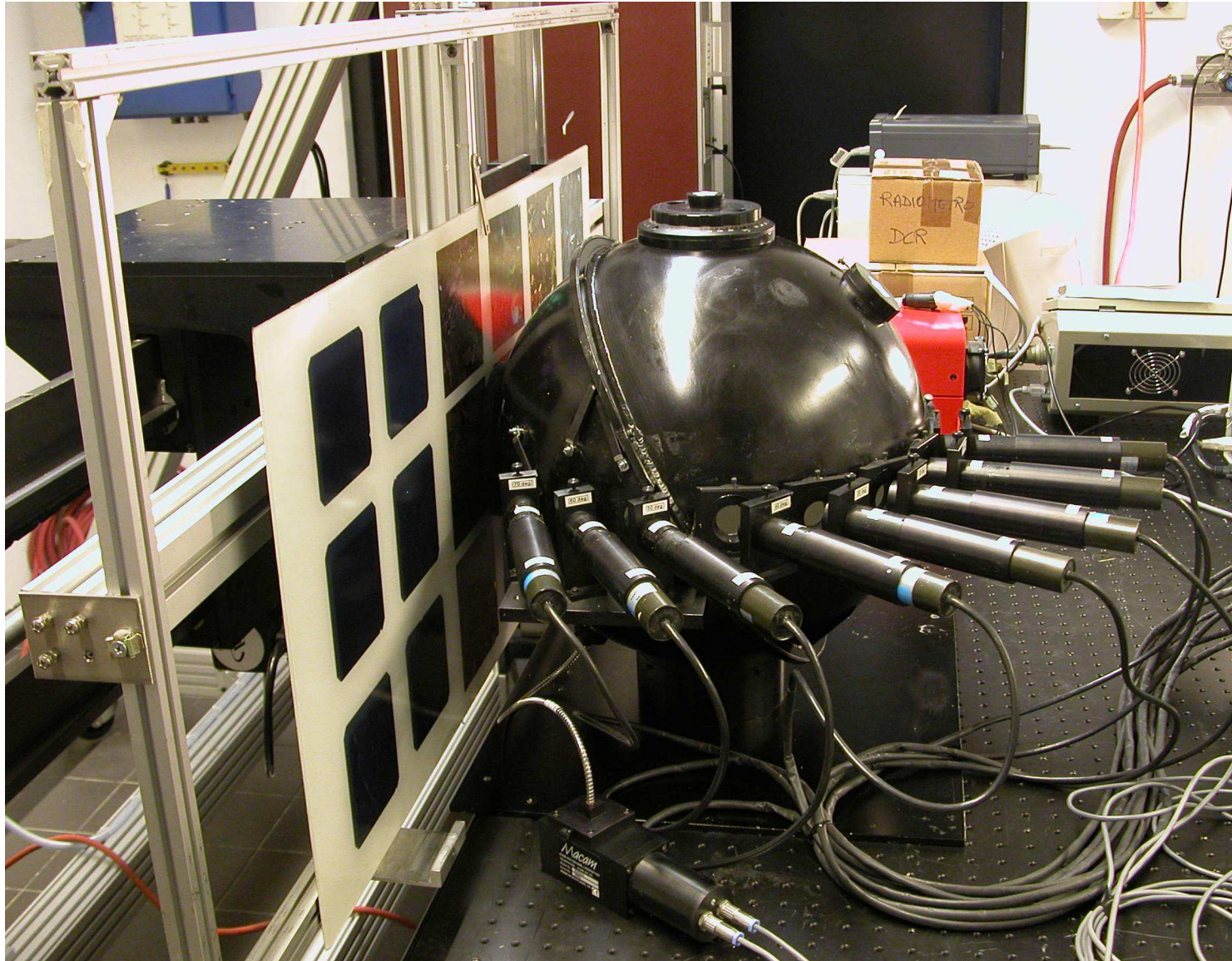


General scheme

# PROM APPARATUS

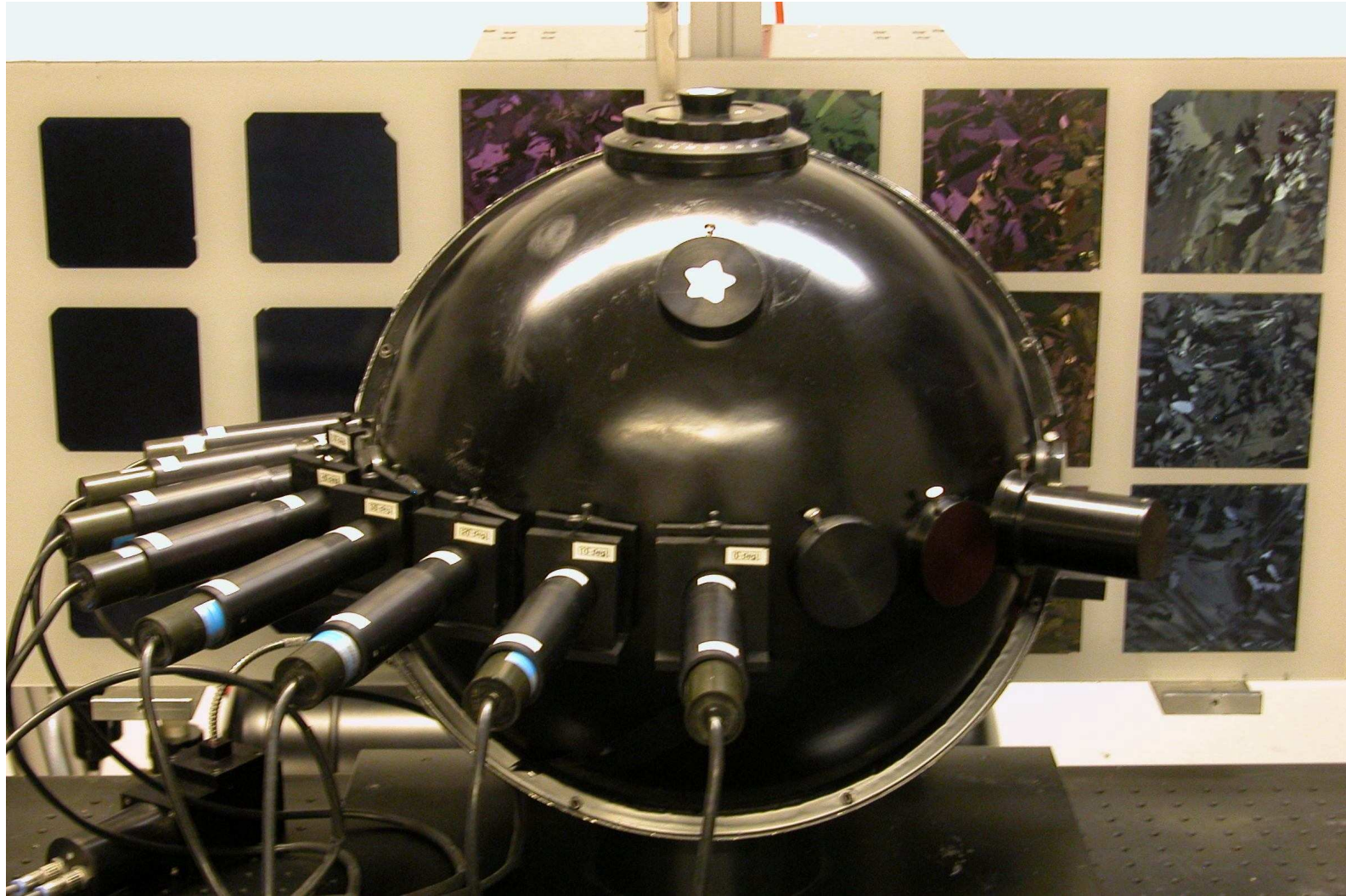


# PROM APPARATUS





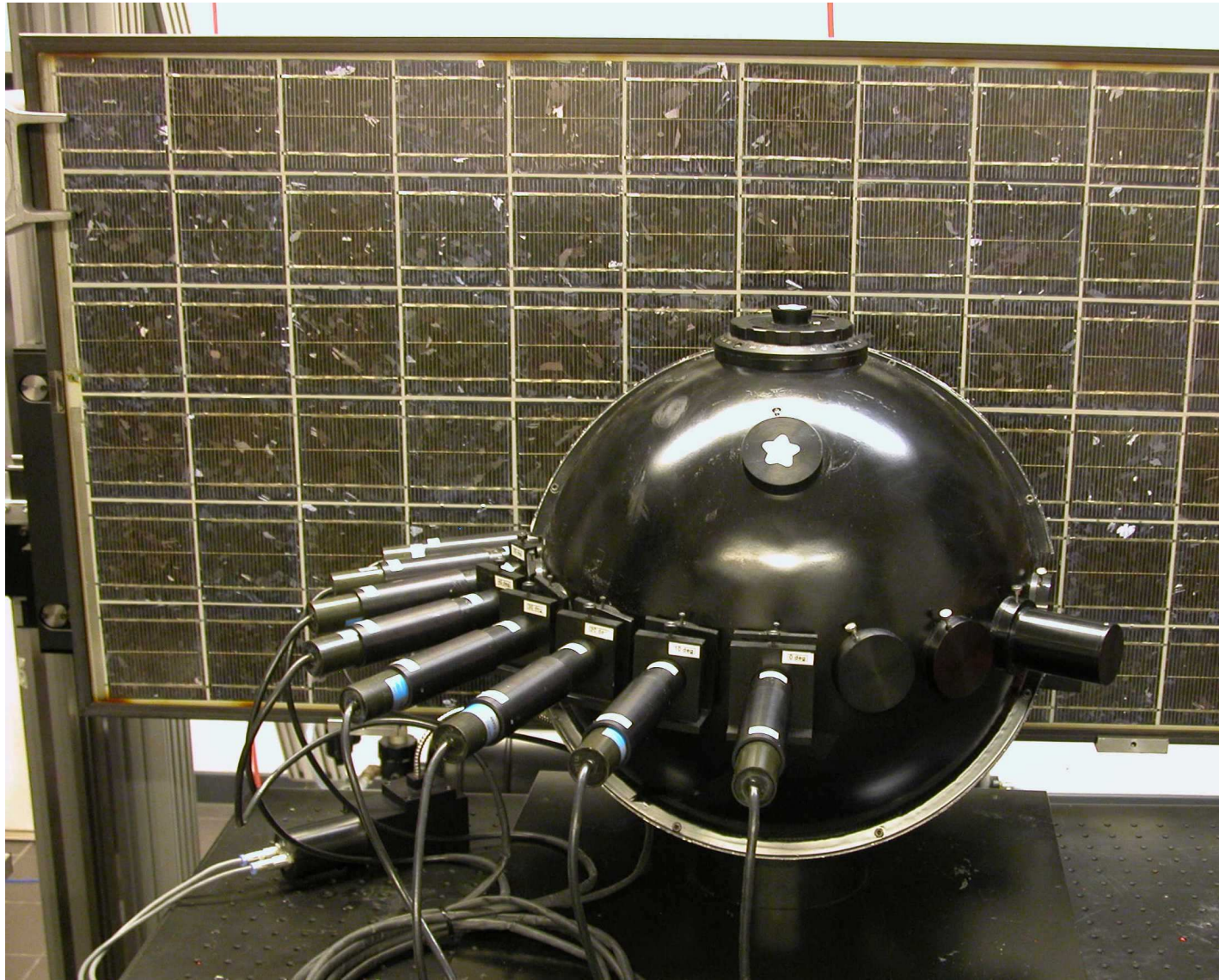
# PROM APPARATUS



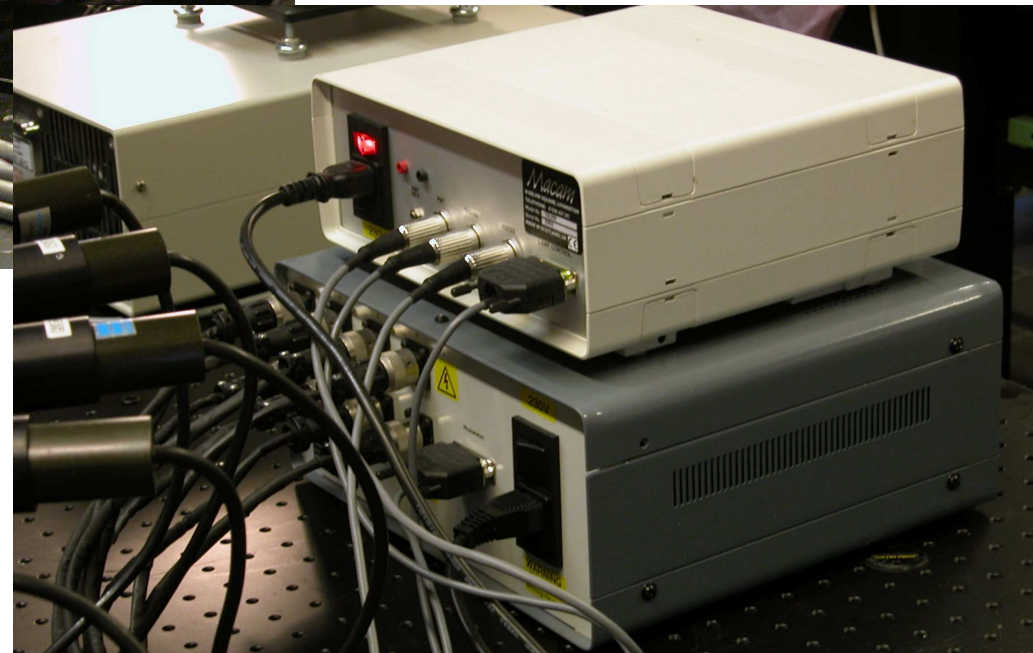
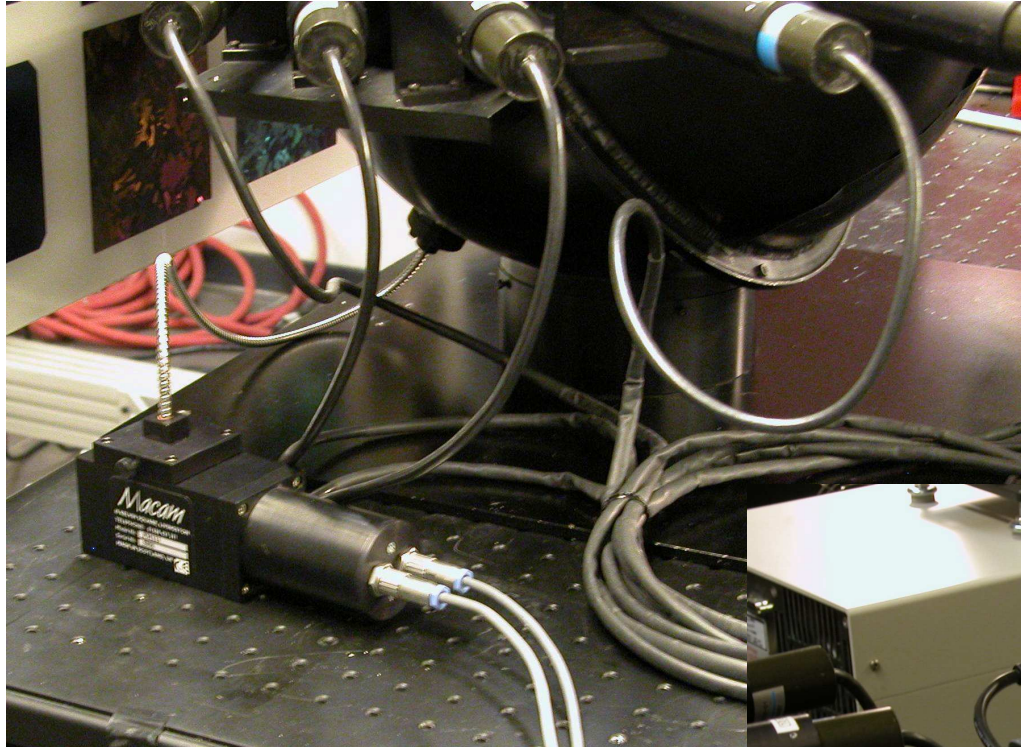
# PROM APPARATUS



# PROM APPARATUS

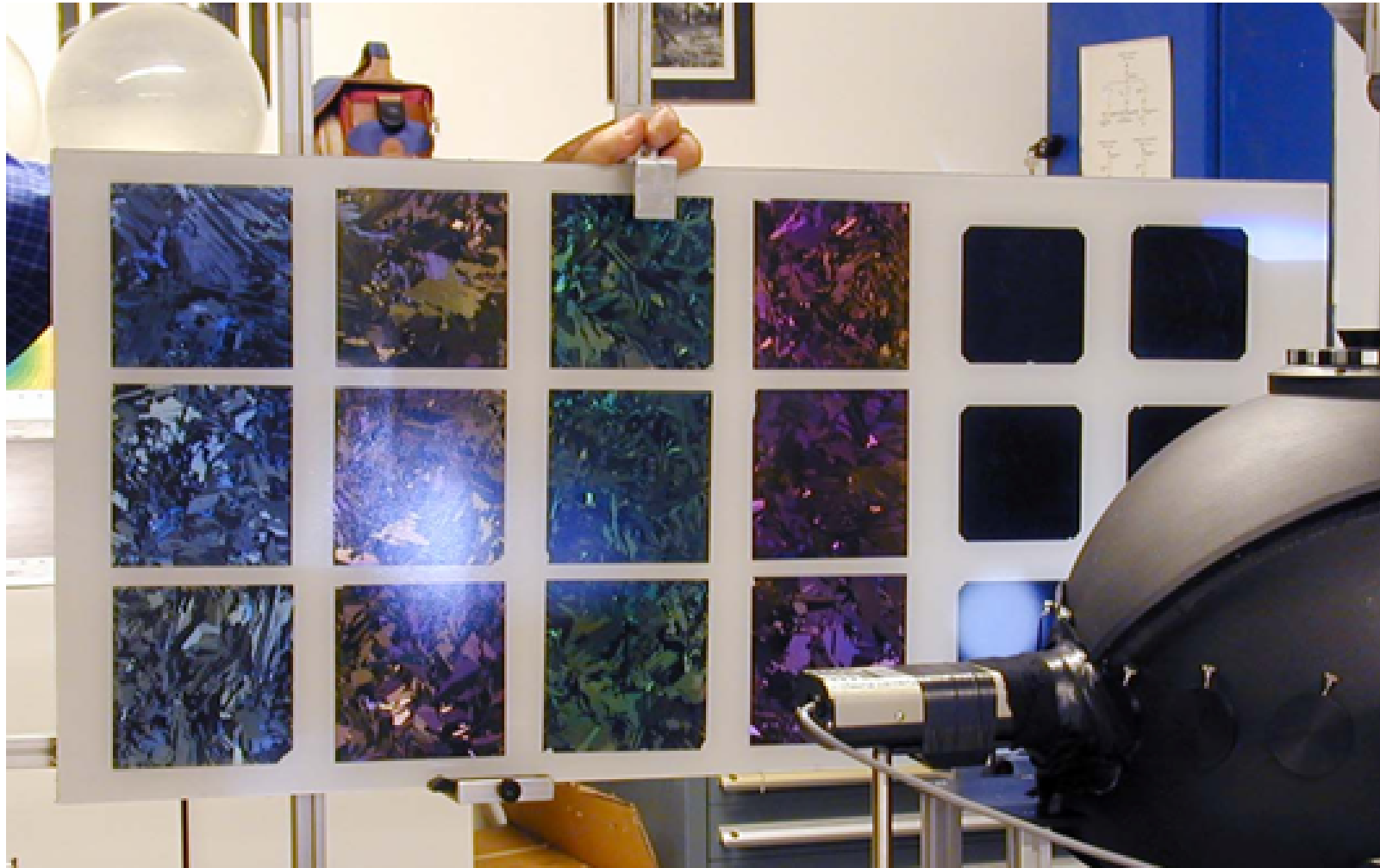


# PROM APPARATUS



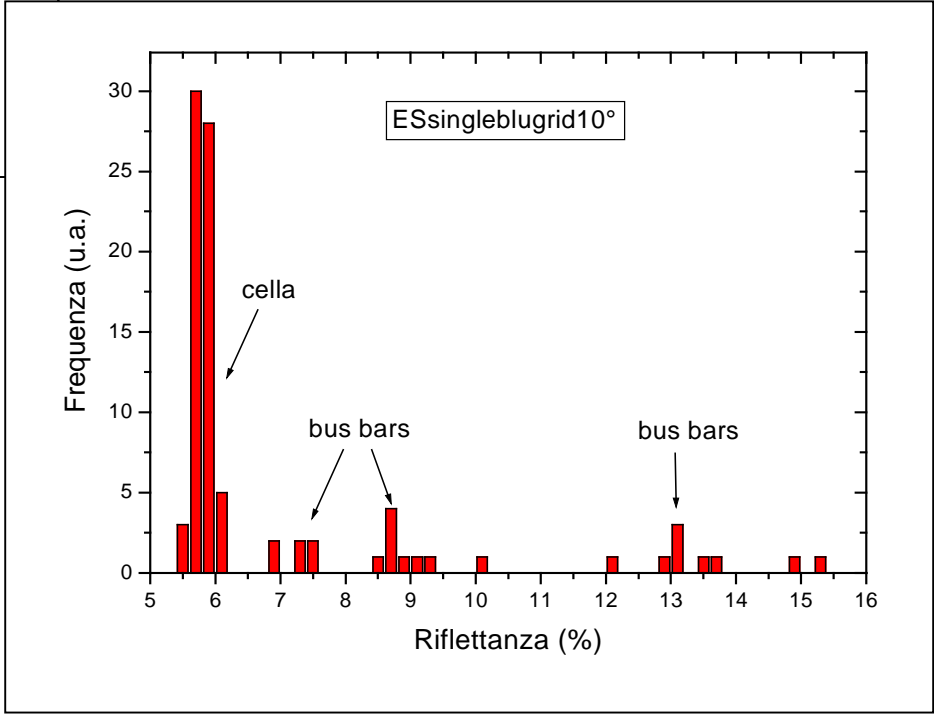
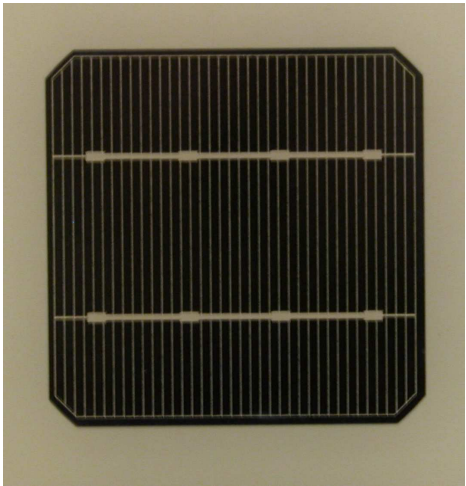
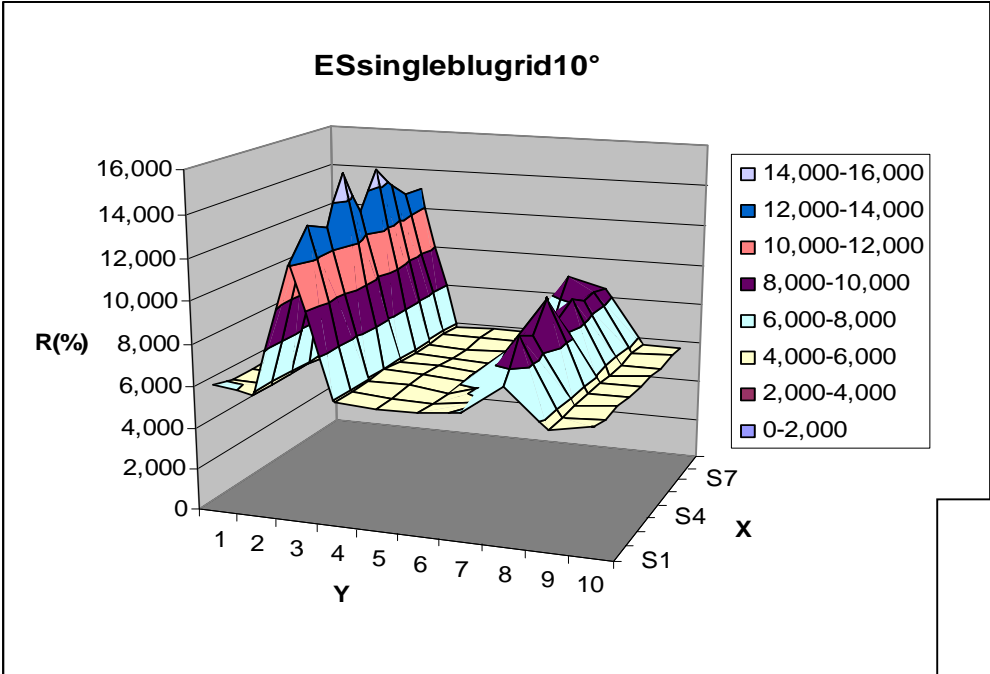
# **OPTICAL MEASUREMENTS**

## SPECIAL EUROSOLARE MODULES

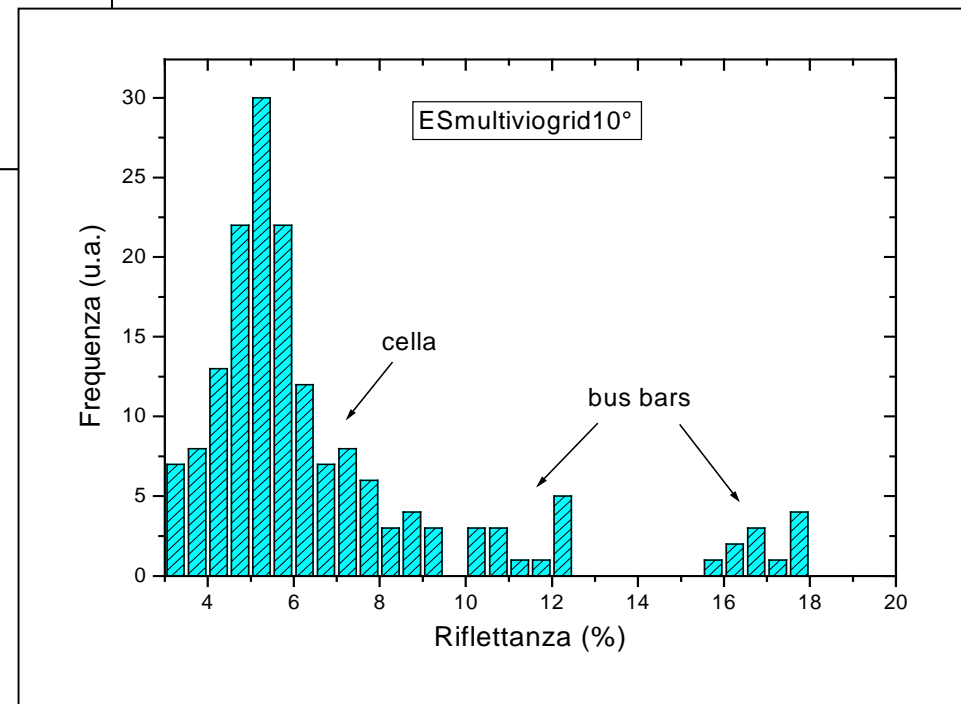
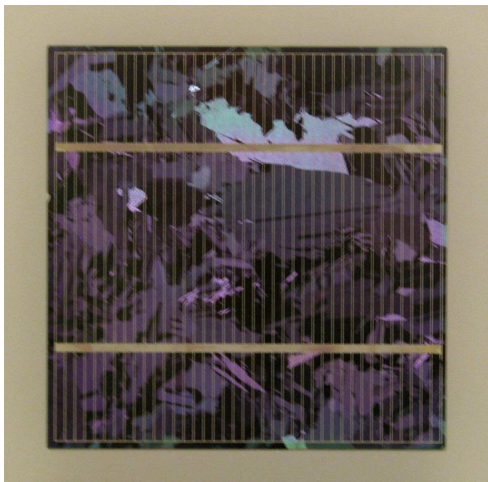
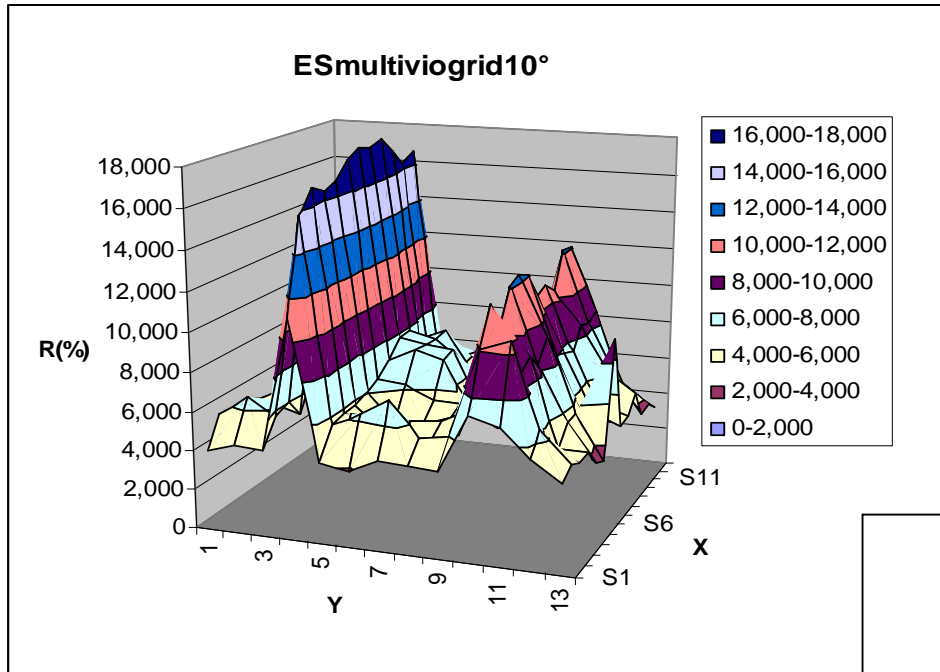


*A. Parretta, A. Sarno, A. Maccari, S. Pietruccioli, F. Ferrazza, It. Pat., Appl. N. RM 2000 A 000634, 1 Dec. 2000.*

# Single-Si blue grid-cells

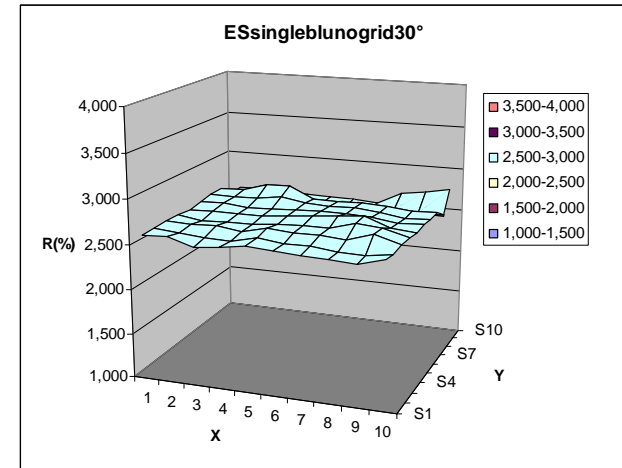
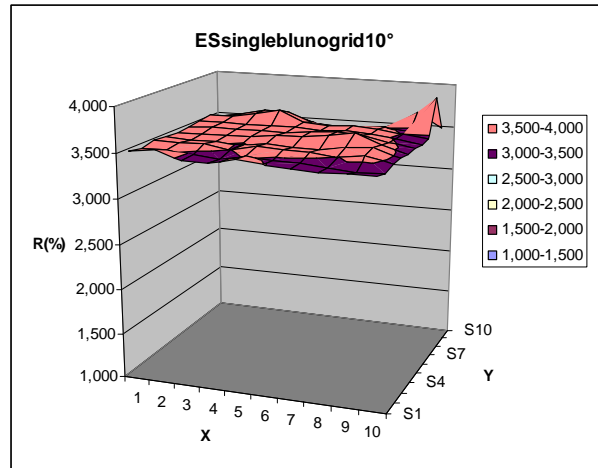
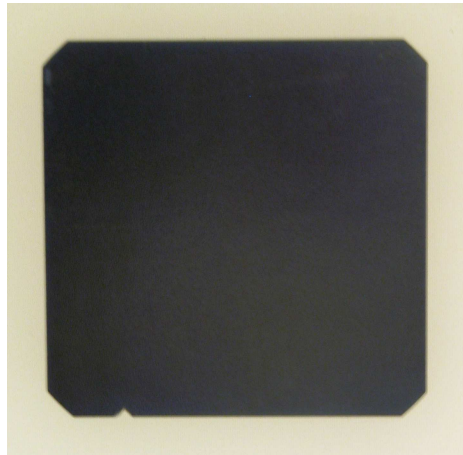


# Multi-Si violet grid-cells



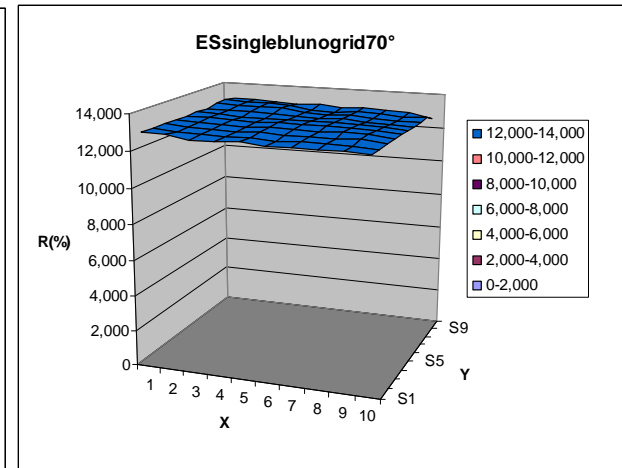
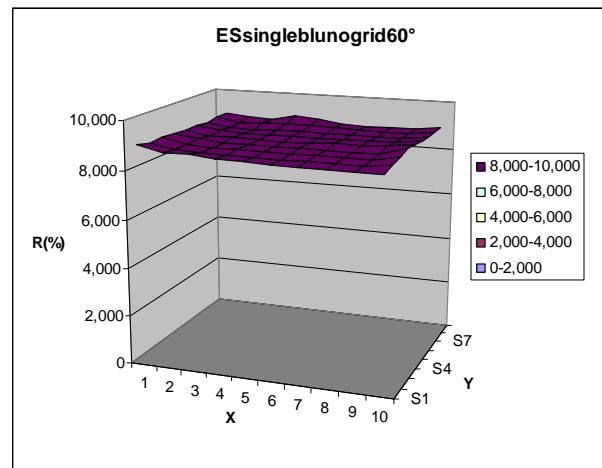
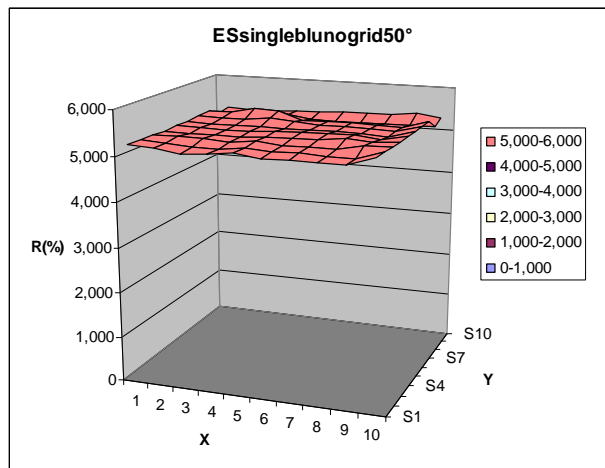


# Single-Si blue gridless-cells



$\theta_{inc} = 10^\circ$

$\theta_{inc} = 30^\circ$

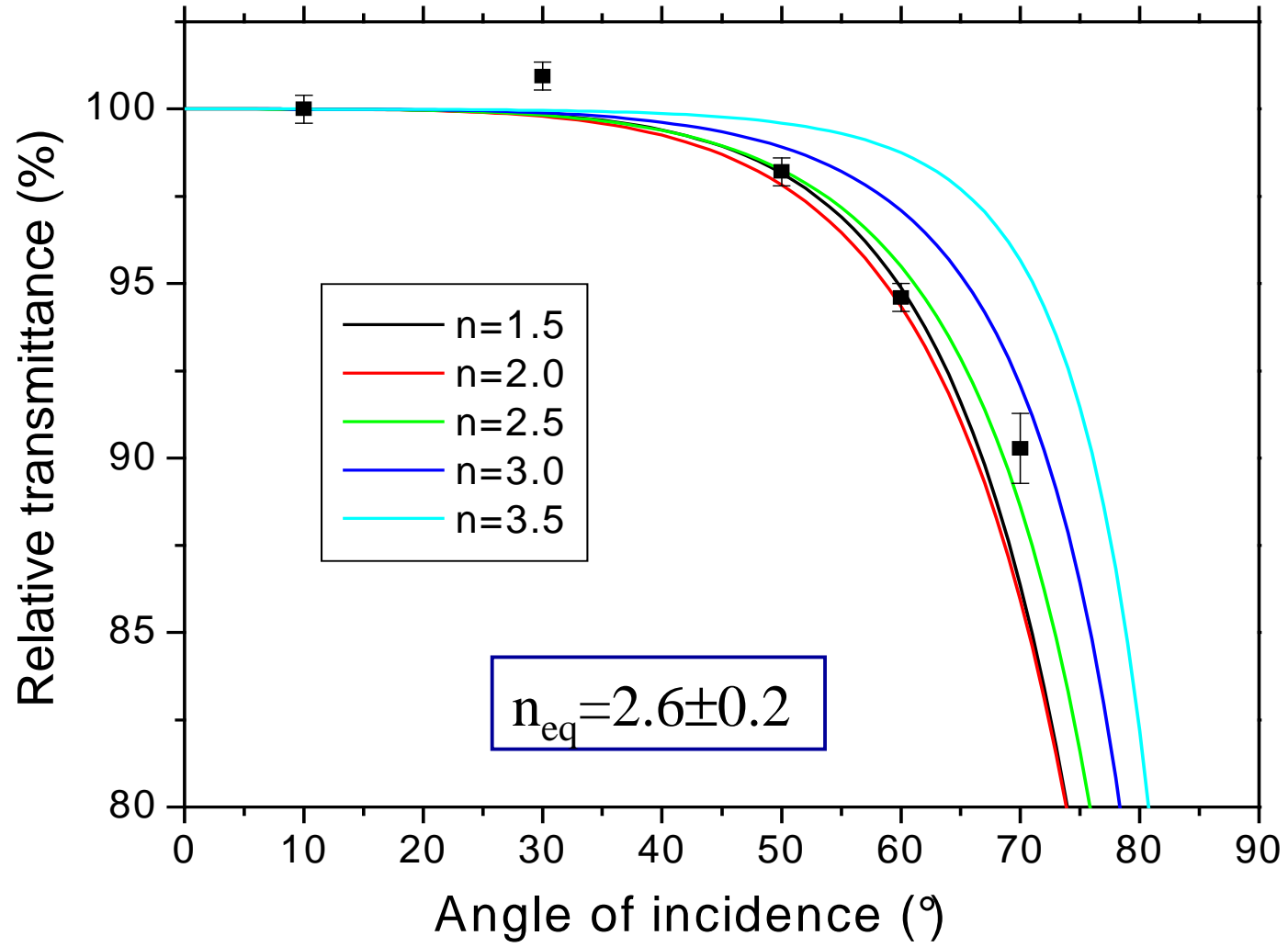


$\theta_{inc} = 50^\circ$

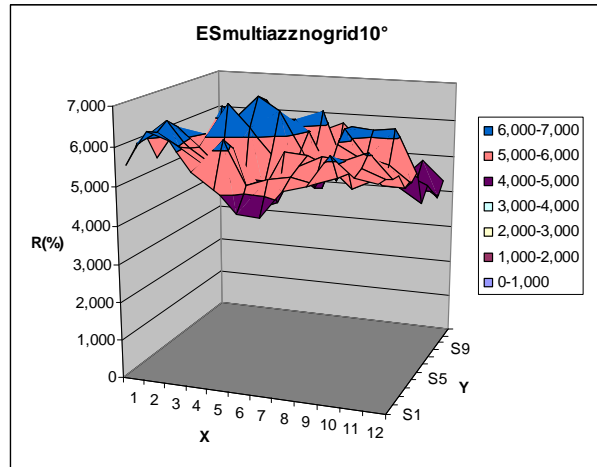
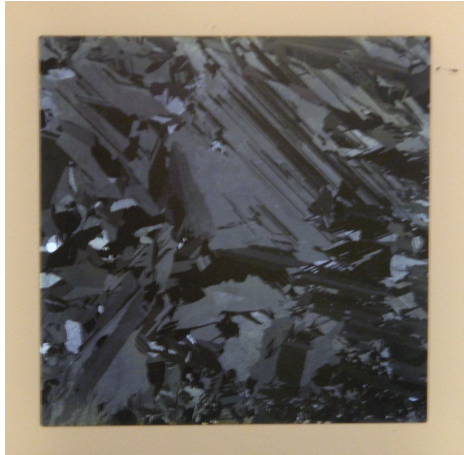
$\theta_{inc} = 60^\circ$

$\theta_{inc} = 70^\circ$

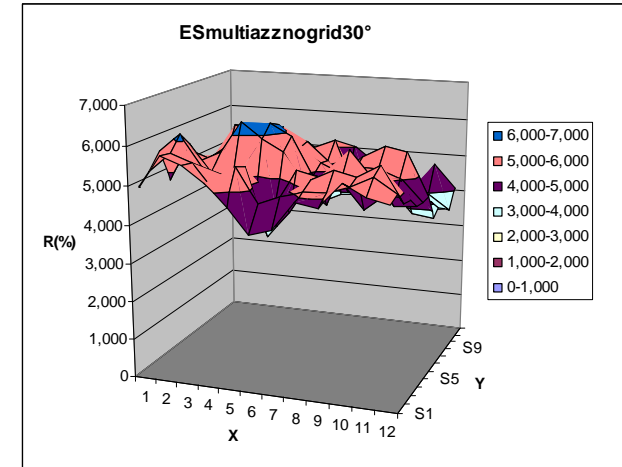
# Single-Si blue gridless-cells



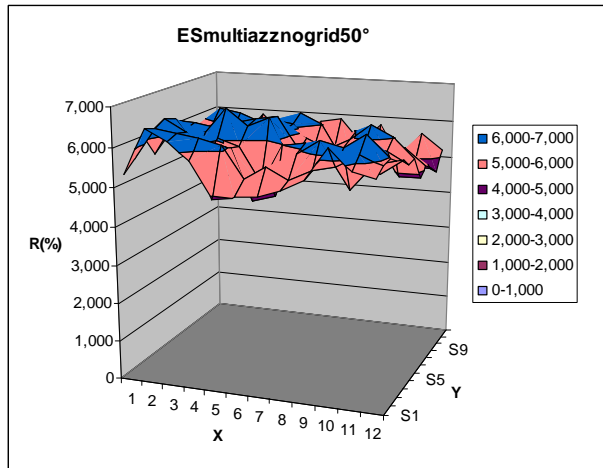
# Multi-Si azure gridless-cells



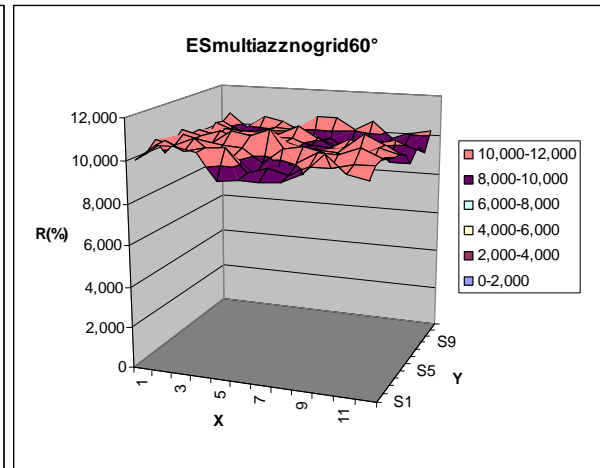
$\theta_{inc}=10^\circ$



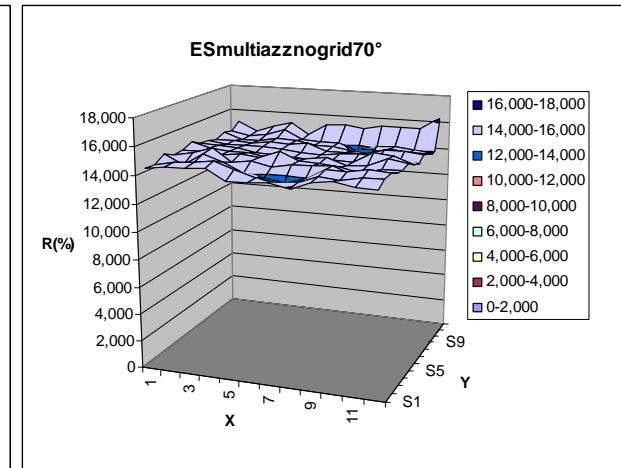
$\theta_{inc}=30^\circ$



$\theta_{inc}=50^\circ$

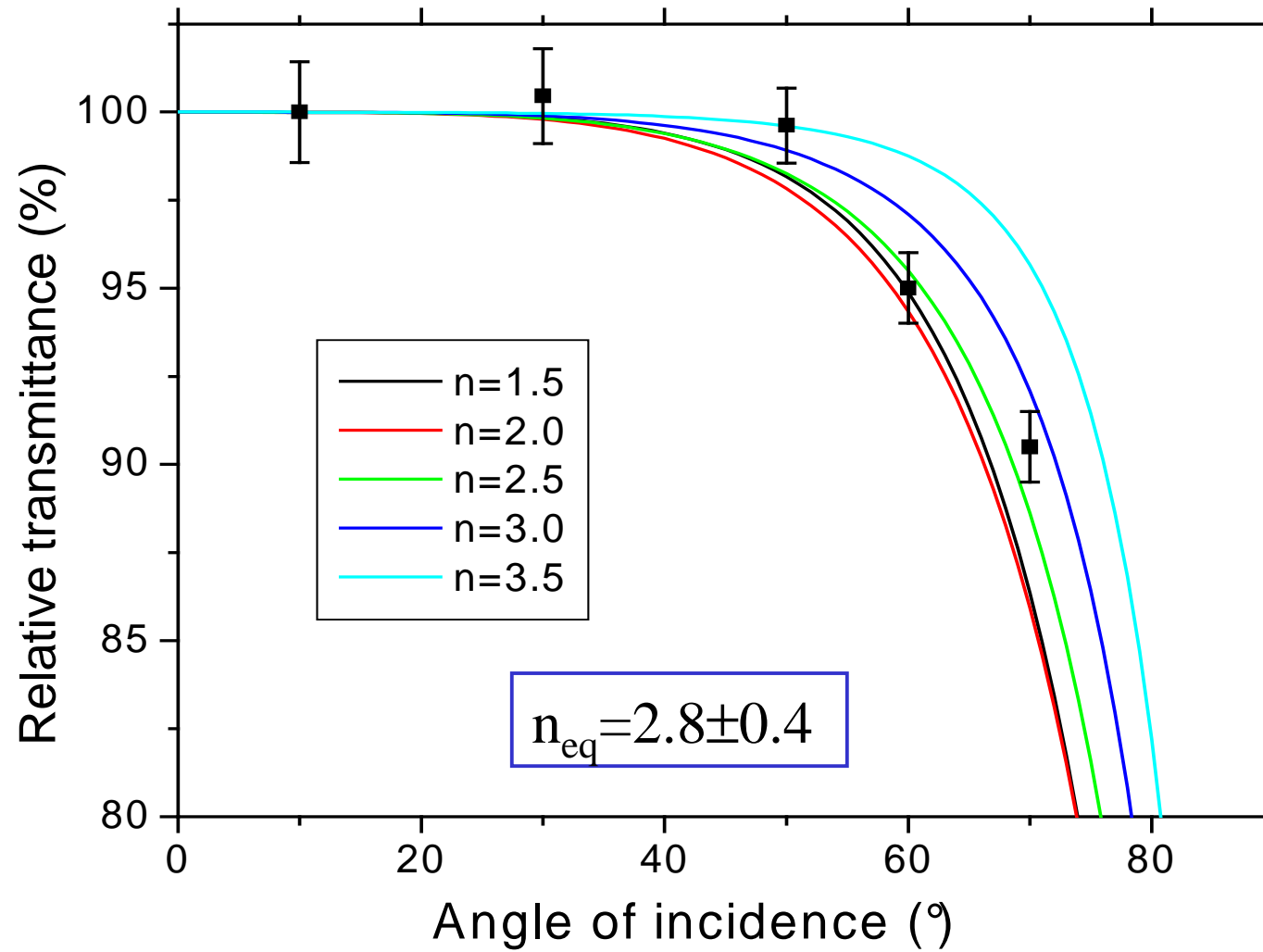


$\theta_{inc}=60^\circ$



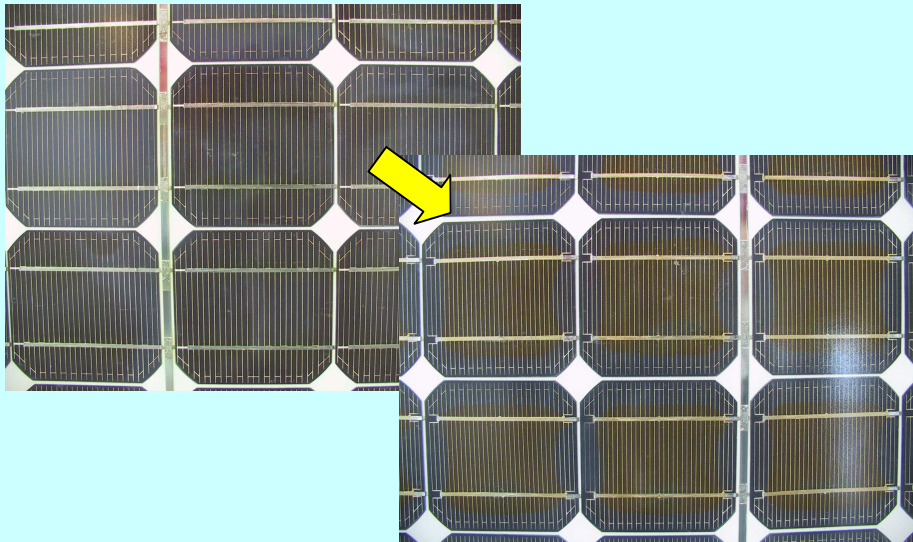
$\theta_{inc}=70^\circ$

# Multi-Si azure gridless-cells

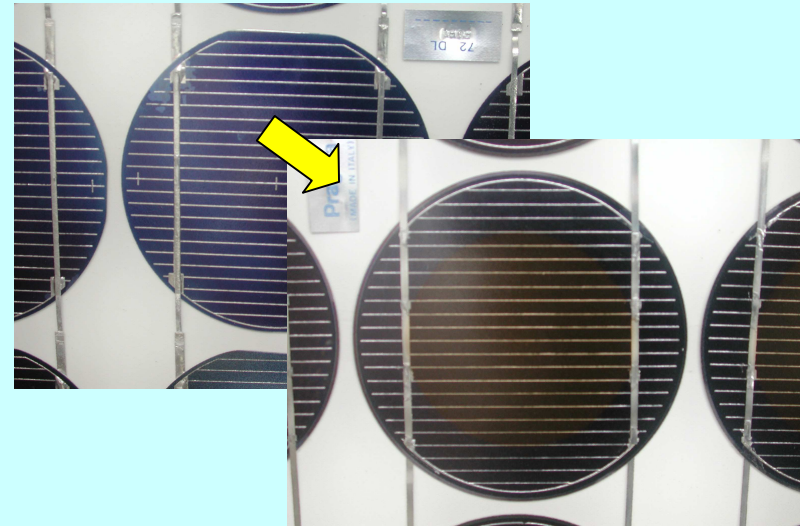


# OPTICAL DEGRADATION OF PV MODULES

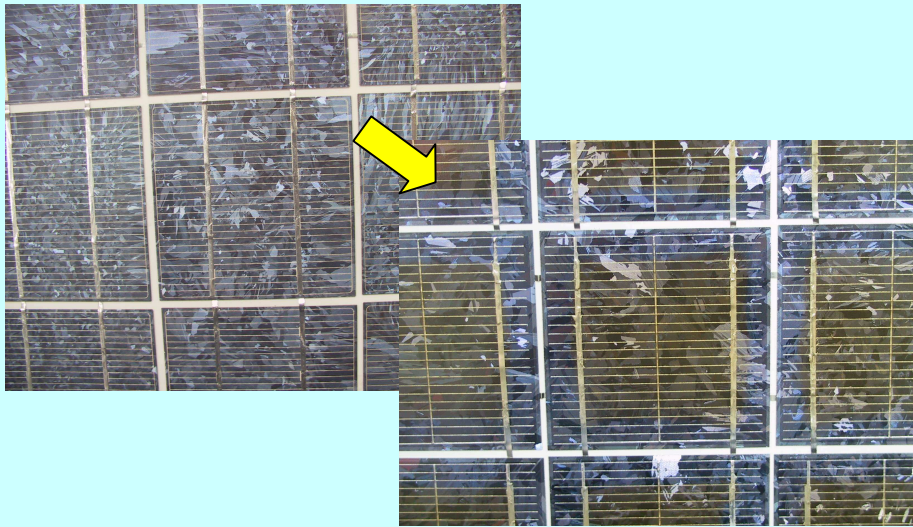
Helios single-Si (text)



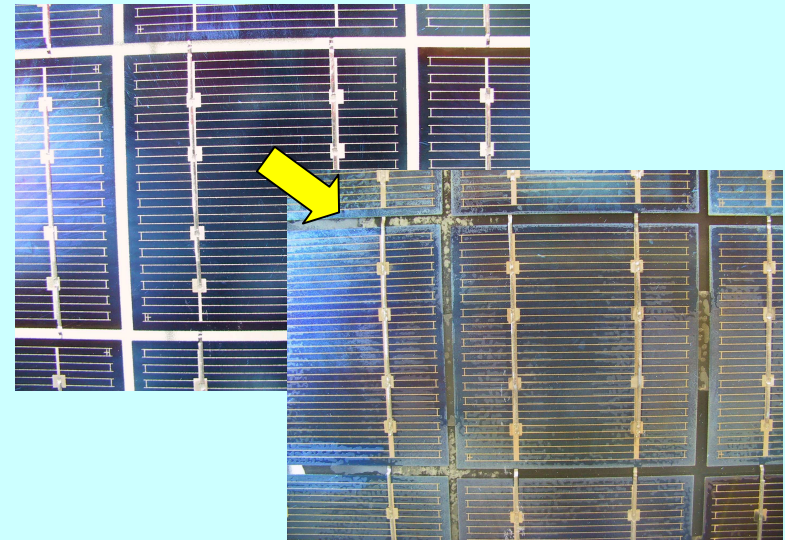
Pragma single-Si (ARC)



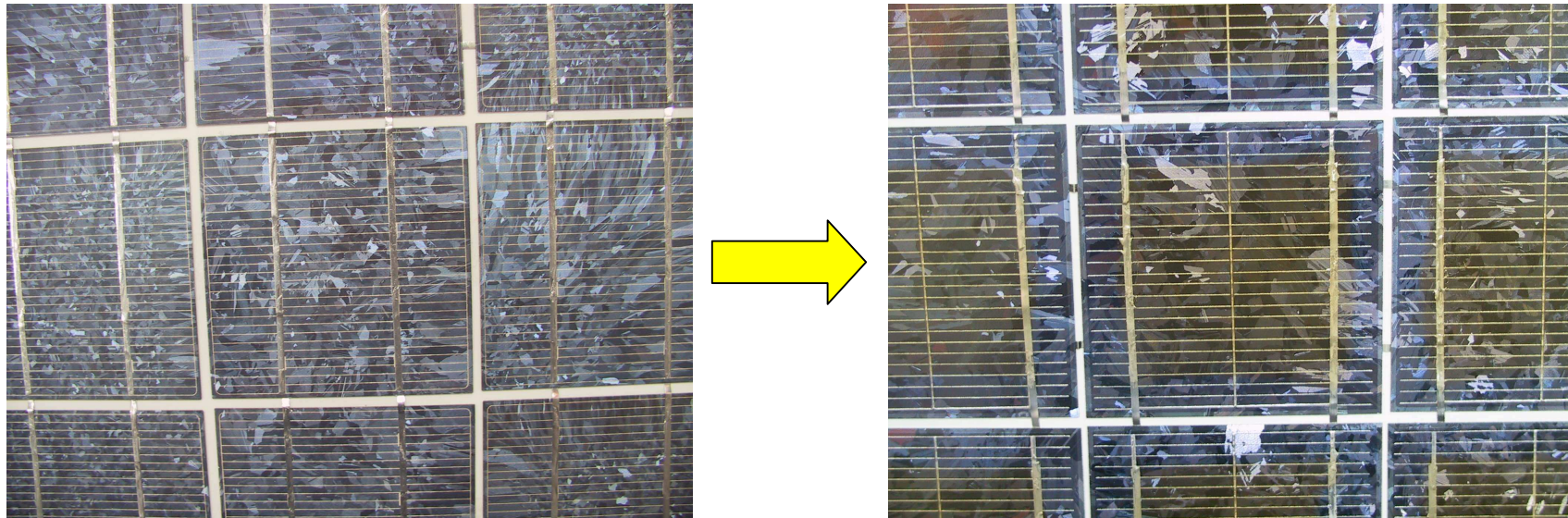
Pragma multi-Si (text)



Ansaldo multi-Si (ARC)

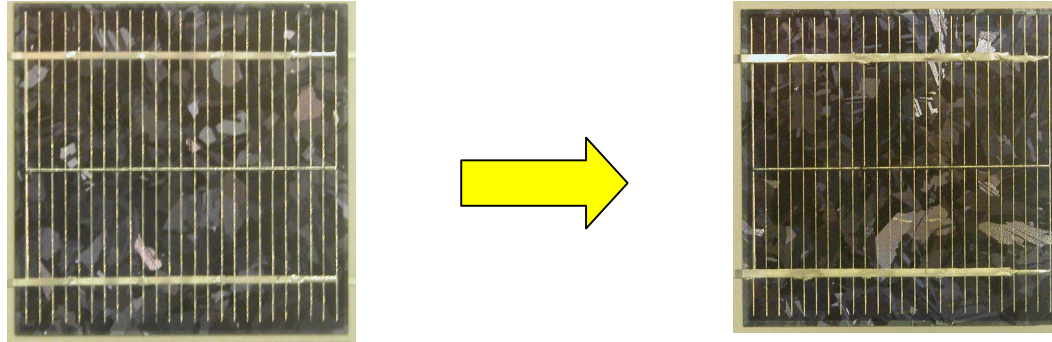


Long-term aging (~ 15 years)

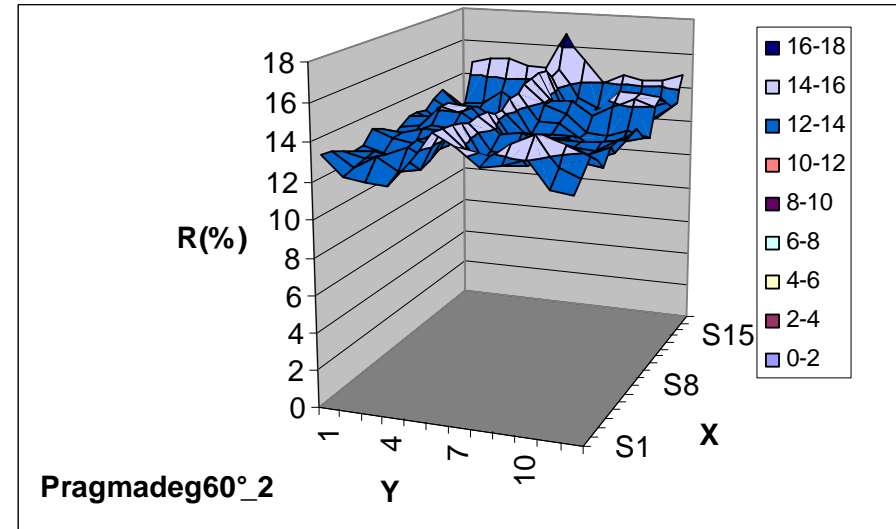
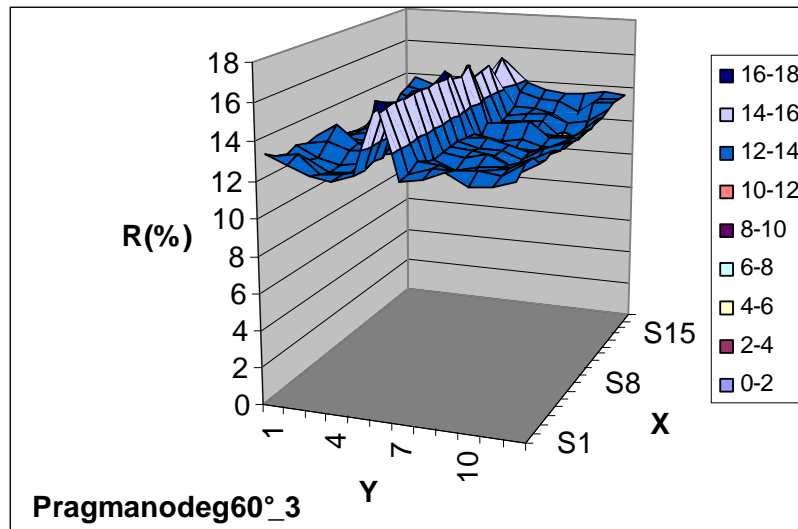


Pragma multi-Si

# Long-term aging (~ 15 years)



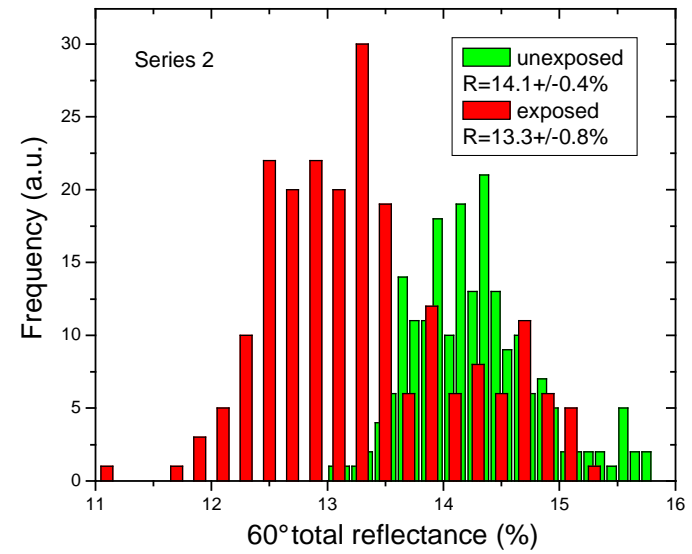
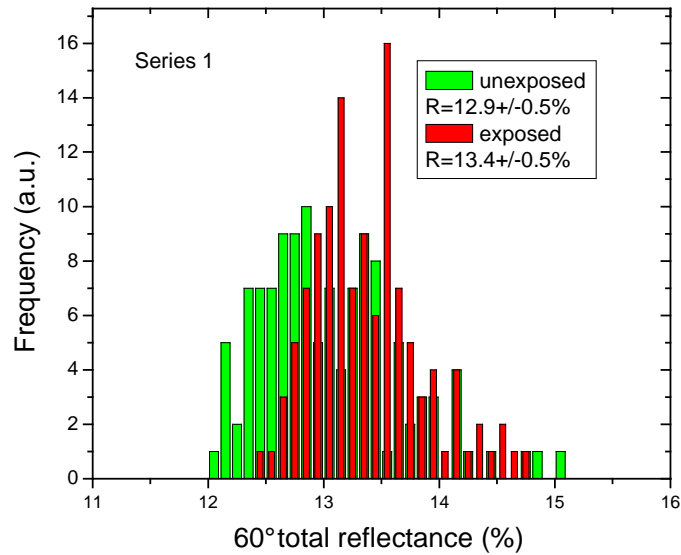
Pragma multi-Si



60° incidence reflectance maps

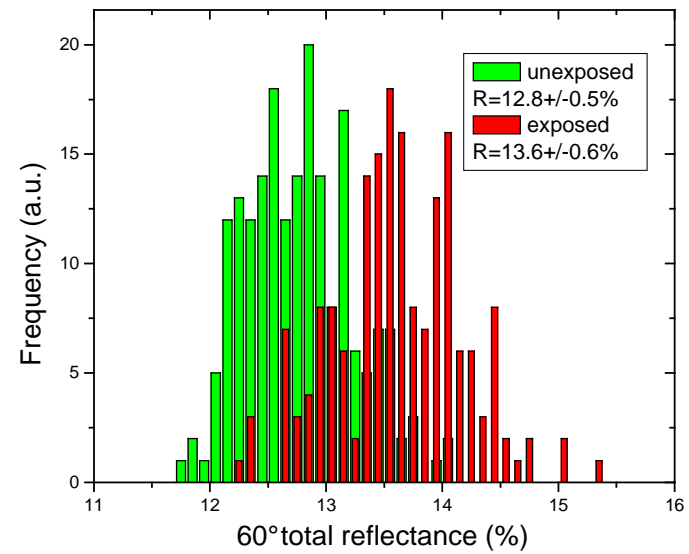


# Long-term aging (~ 15 years)

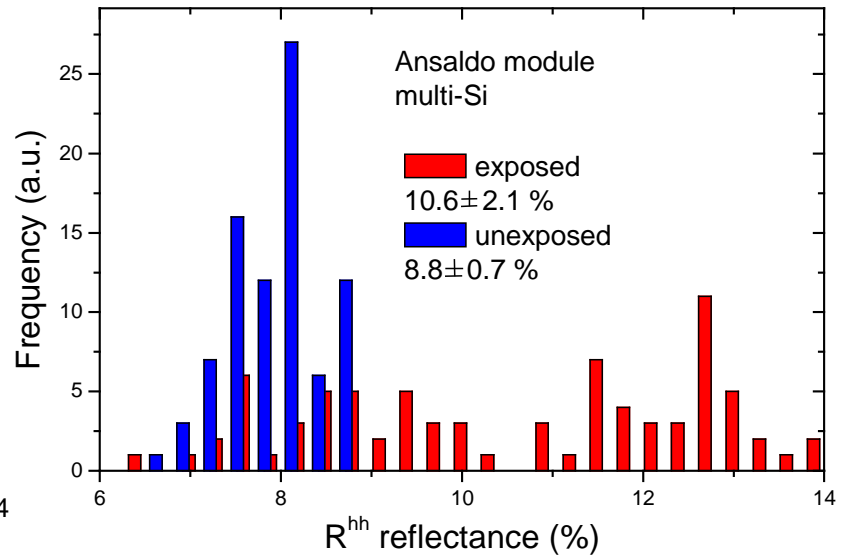
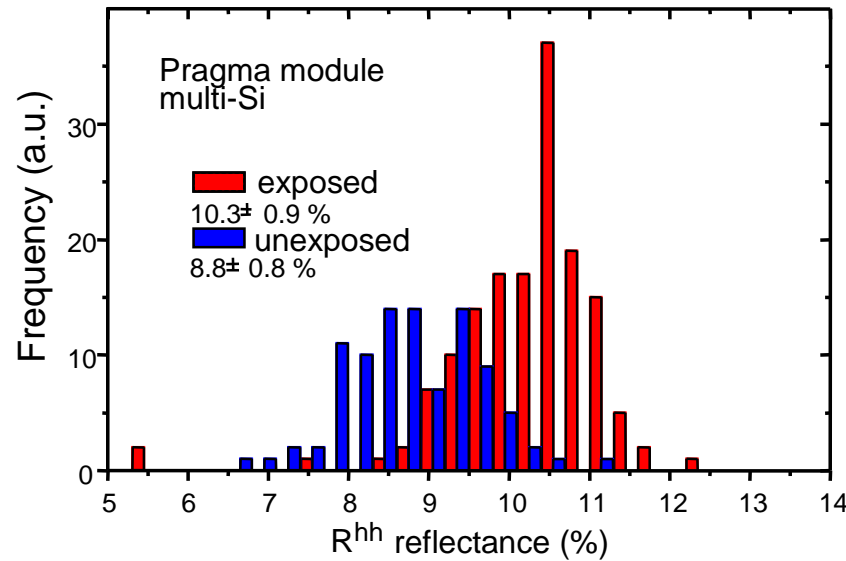
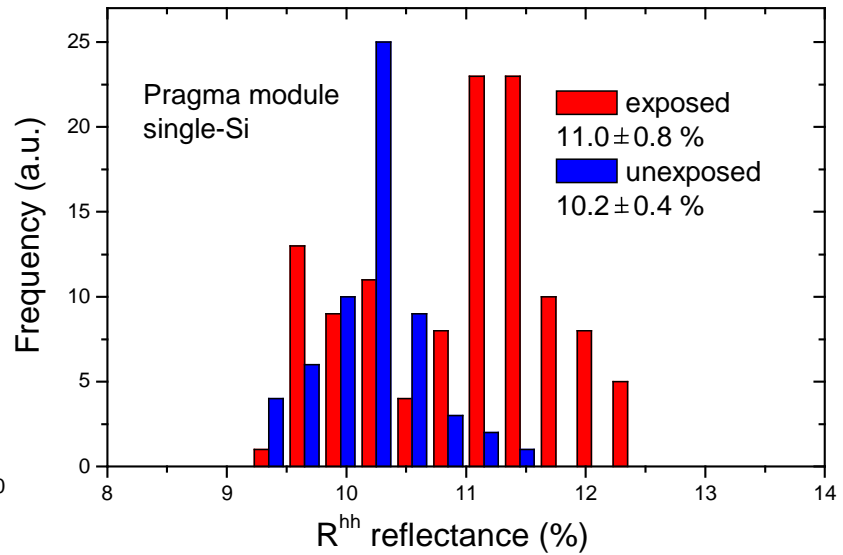
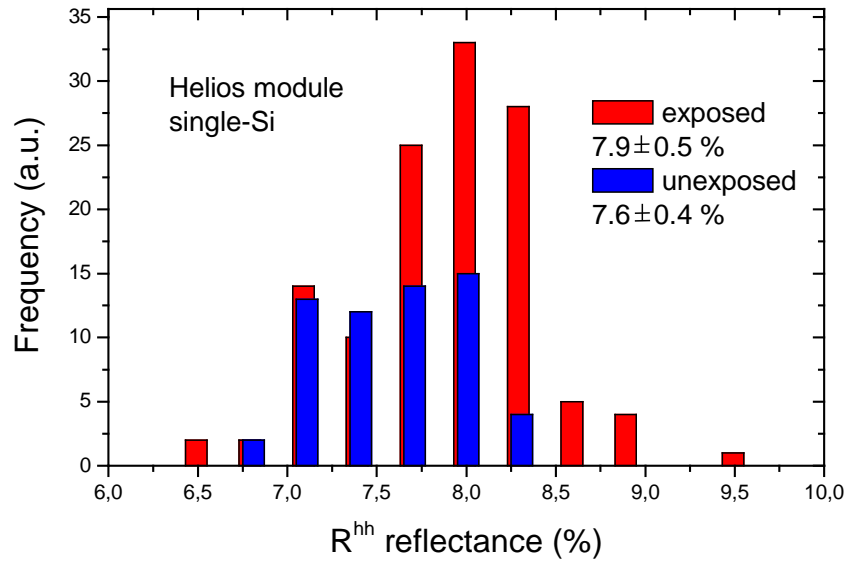


Pragma multi-Si

60° incidence reflectance  
Frequency distribution maps



# HEMISPHERICAL / HEMISPHERICAL REFLECTANCE

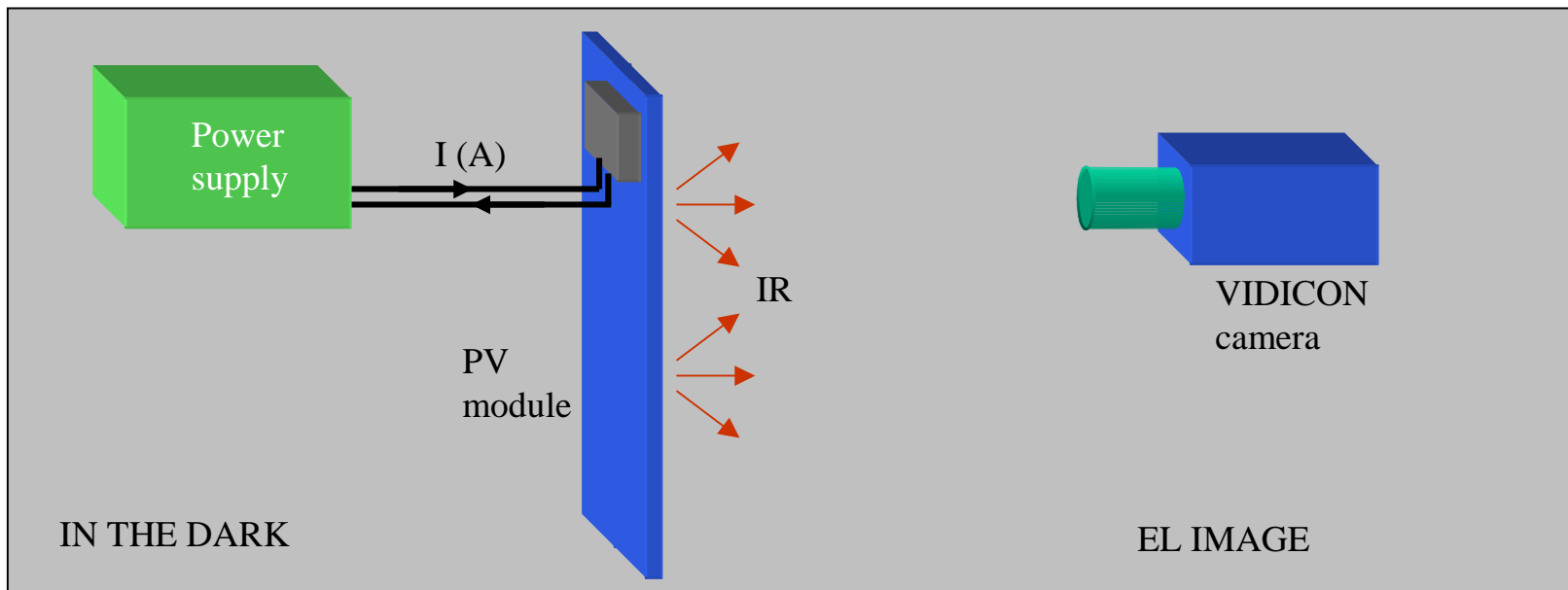
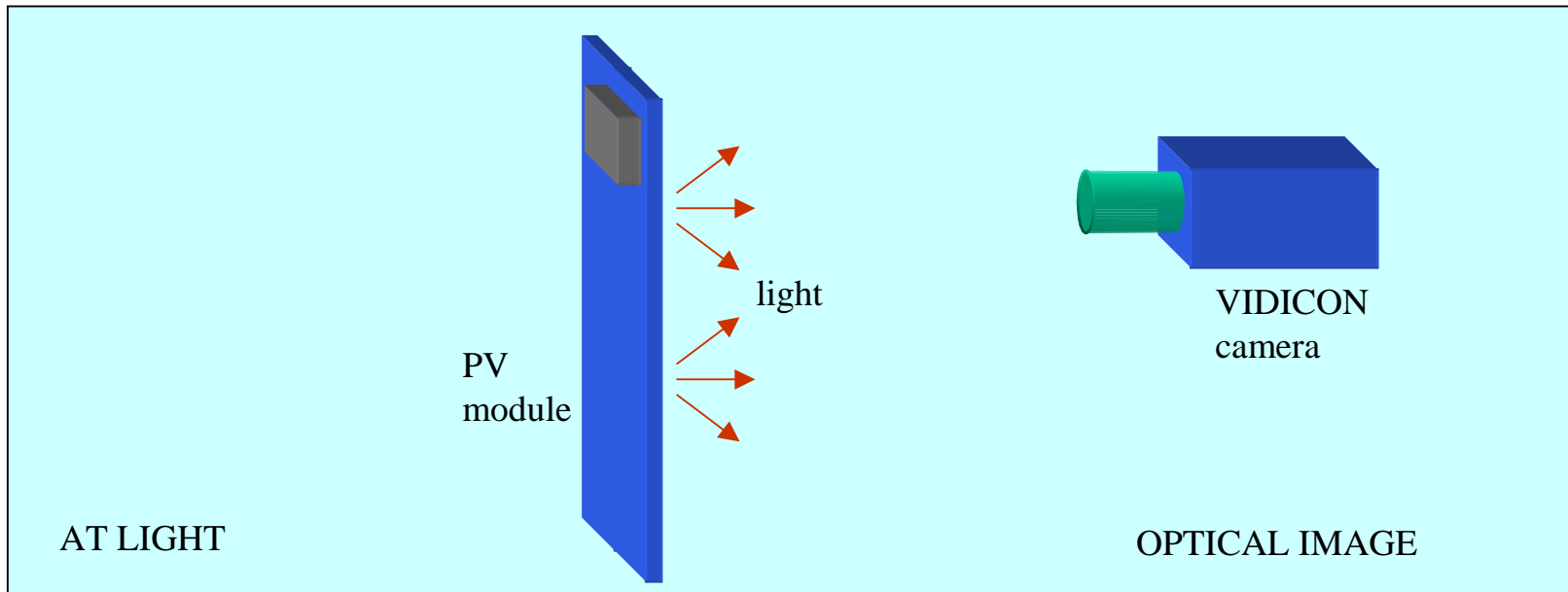


OPTICAL IMAGES

VS.

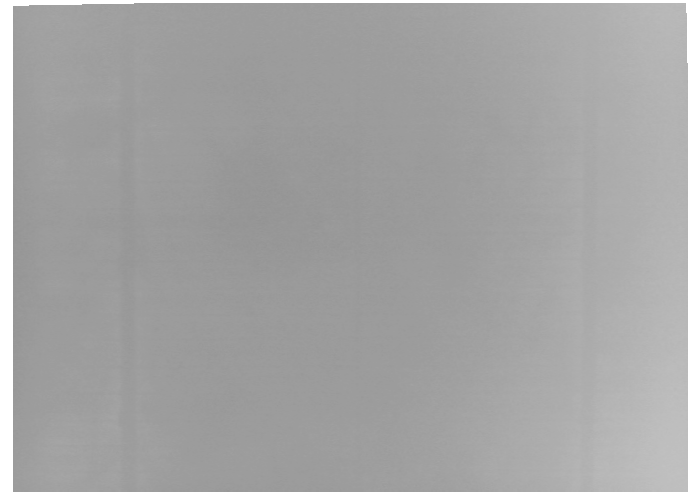
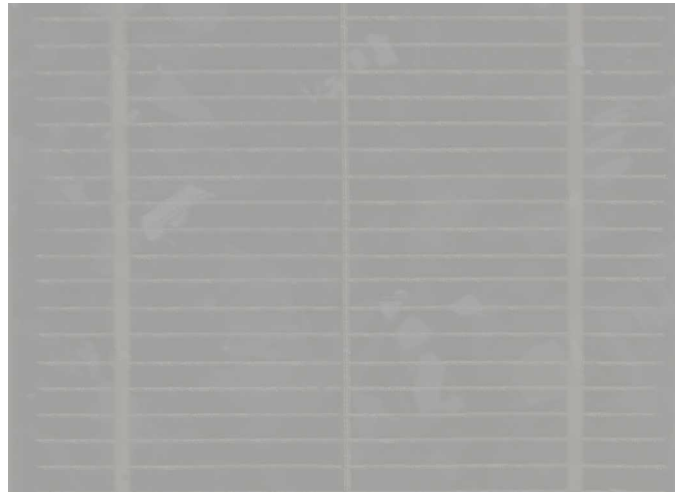
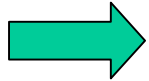
ELECTROLUMINESCENCE IMAGES

# Optical and EL images

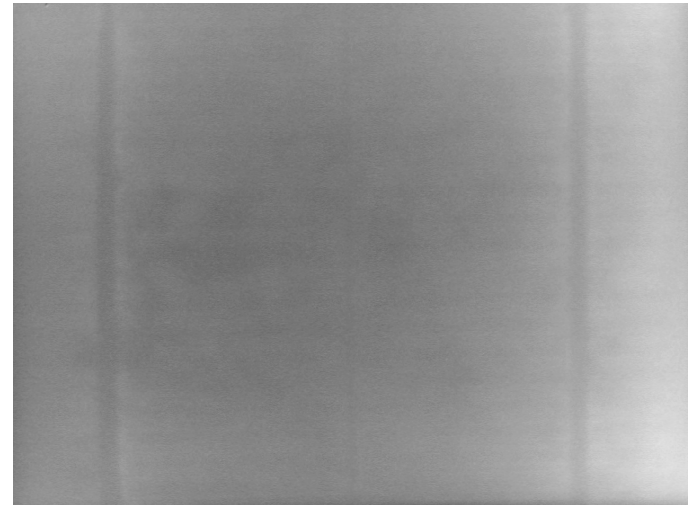
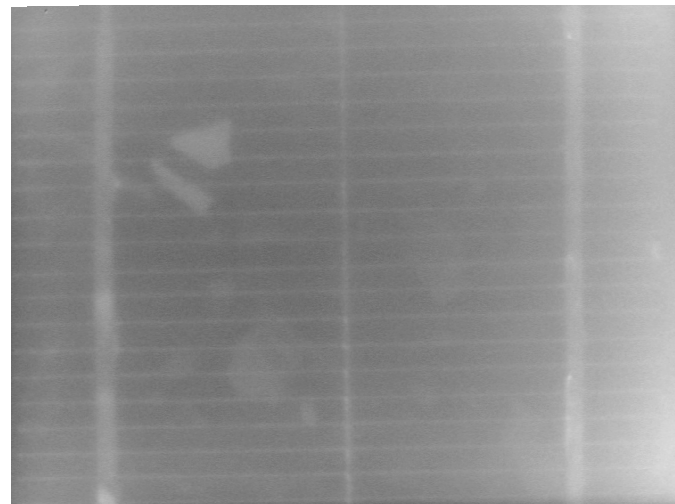
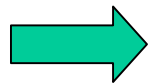


# Pragma multi-Si modules

Unexposed  
module



Exposed  
module



Optical images

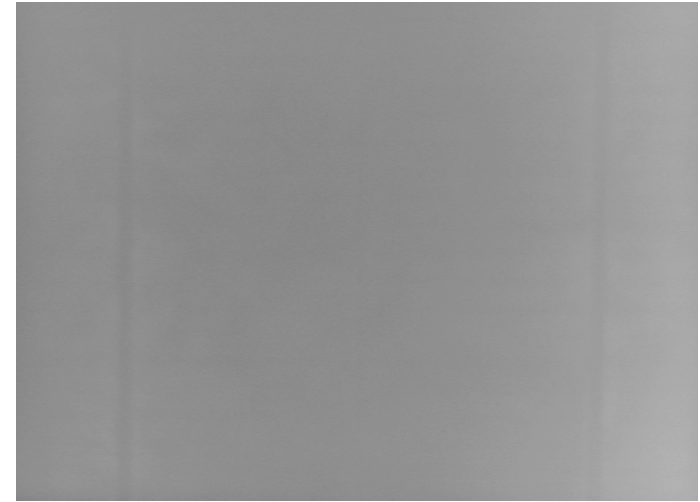
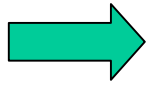


EL images

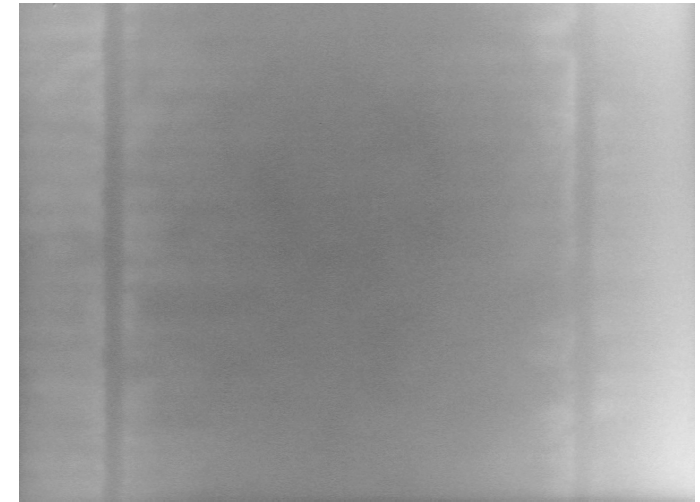
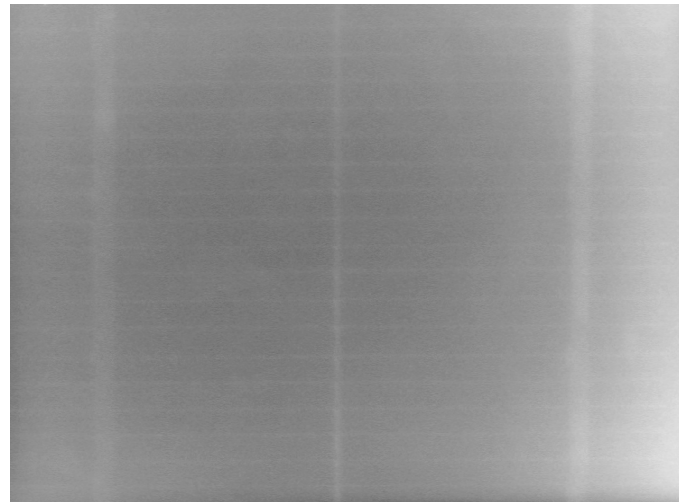
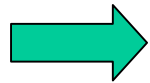


# Pragma multi-Si modules

Unexposed  
module



Exposed  
module



Optical images

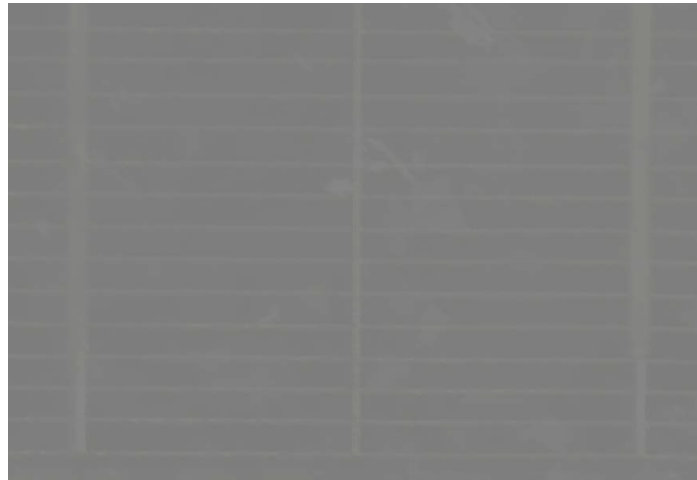
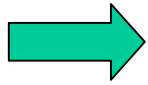


EL images

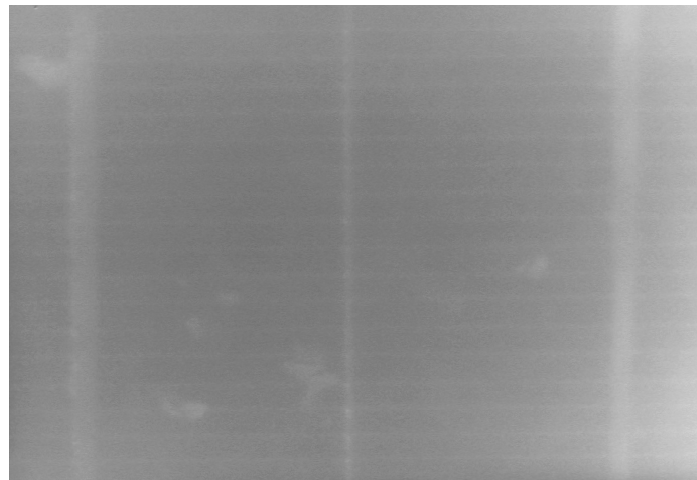
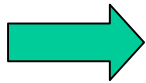


# Pragma multi-Si modules

Unexposed  
module



Exposed  
module



Optical images



EL images



## CONCLUSIONS

We have presented a method and an apparatus (PROM) for the fast optical mapping of a PV module.

The features of the method are:

- the light source is pulsed, suitable for fast measurements ( $\sim 1$  s);
- a series of pulsed lamps are used in sequence, one for each incidence angle;
- quasi-simultaneous optical maps of the module at different incidence angles can be carried out;
- the use of pulsed lamps reduces the energetic budget and limits the heating of components, improving the reliability of measurement;
- with integrated modules (a-Si, CIS, etc.) the method allows to combine optical and electrical measurements;

Optical measurements are well correlated with EL measurements.