



Preparation and Investigation of Silicon PIN Solar Cells

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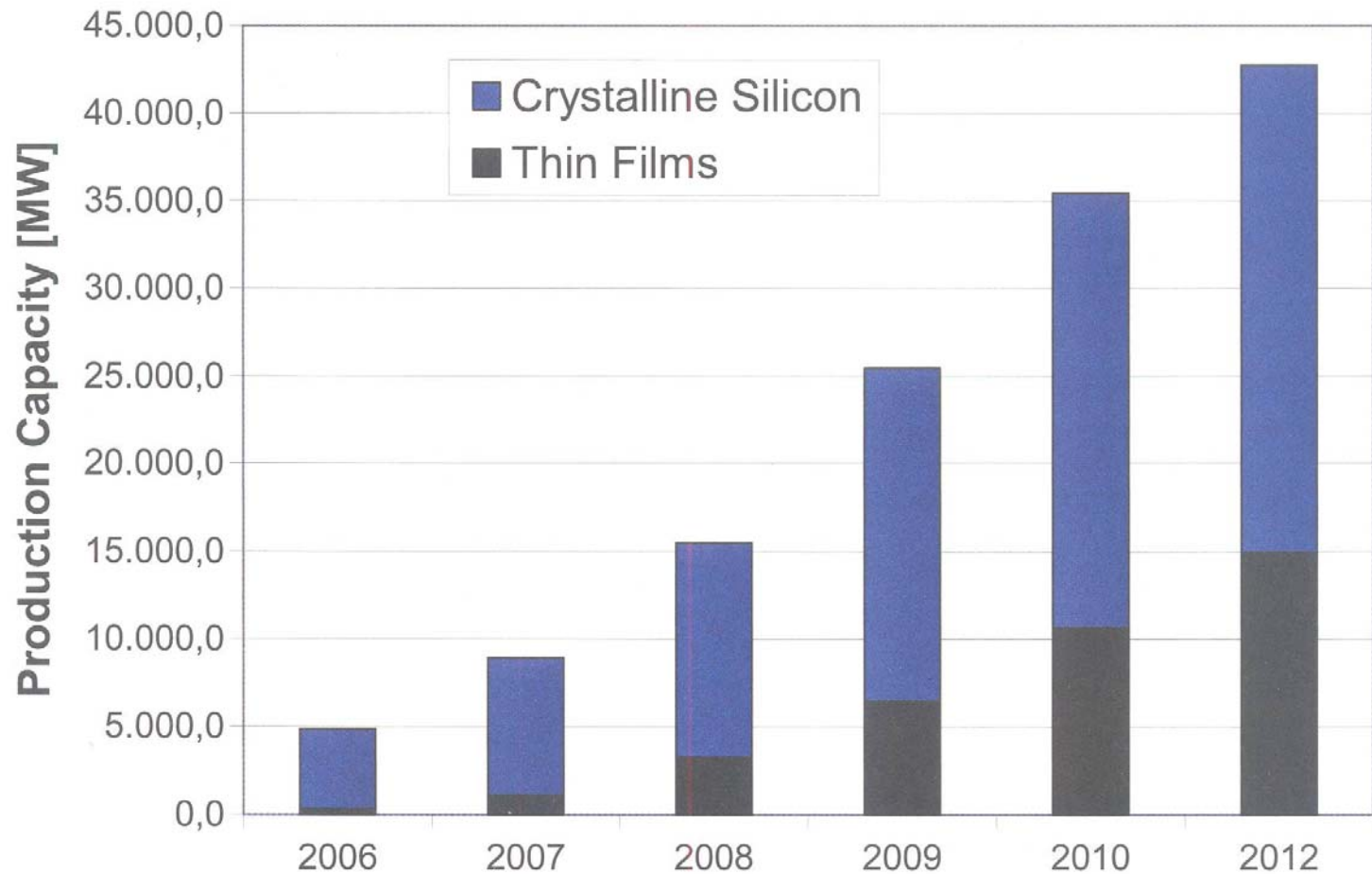
***ISES Annual Meeting
Weizmann Institute of Science,
Rehovot, September 9, 2009***

Background



Solar cells are devices which convert solar energy directly into electricity via the photovoltaic effect.

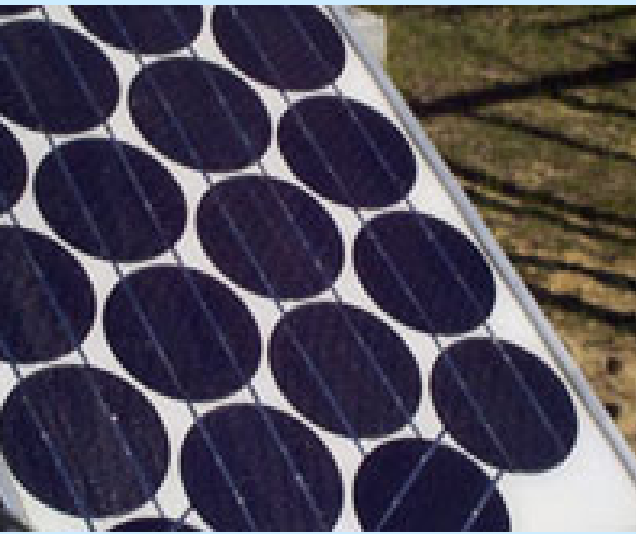
PV Production Capacities



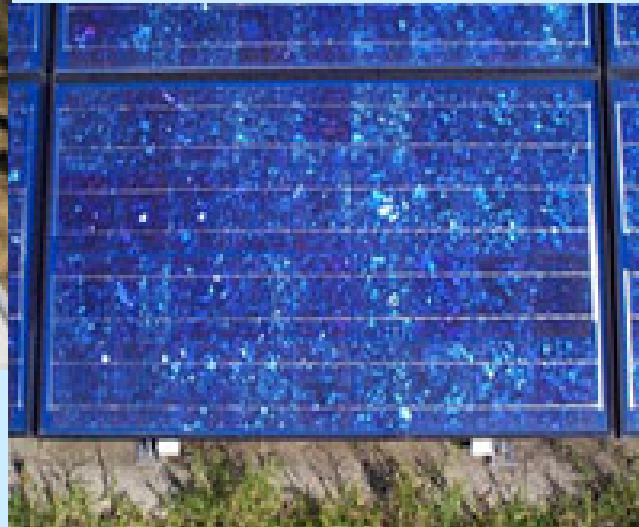
Silicon solar cells

$$\eta_{s_lim} = 1 - \frac{4 T_0}{3 T_S} + \frac{1}{3} \left(\frac{T_0}{T_S} \right)^4 \quad \eta_{s_lim} = 93\%$$

Single-crystalline Si



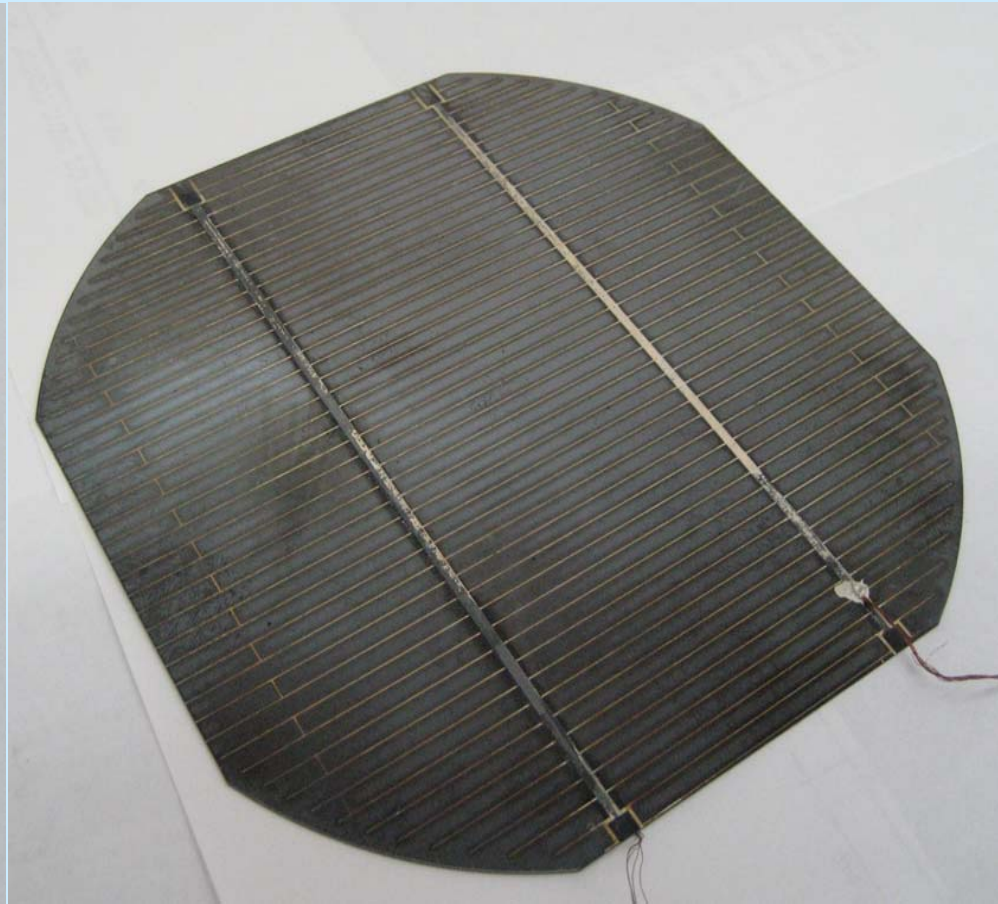
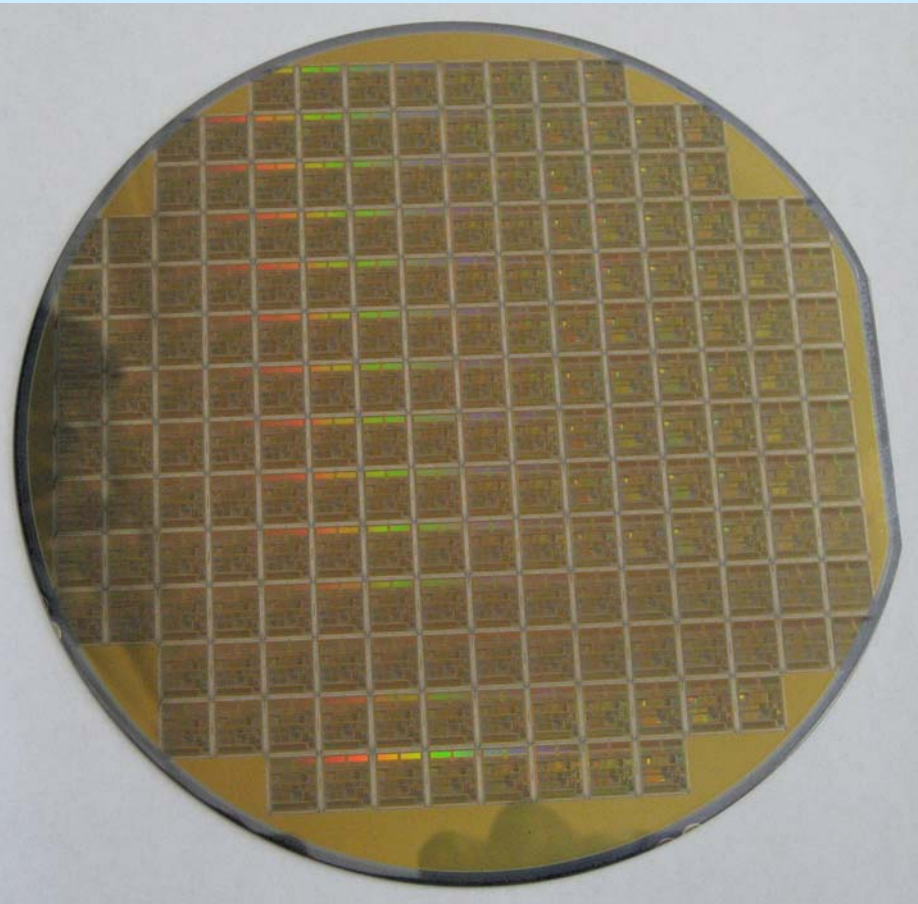
Poly-crystalline Si



Amorphous Si



Computer Chips on a Wafer and Silicon Solar Cells



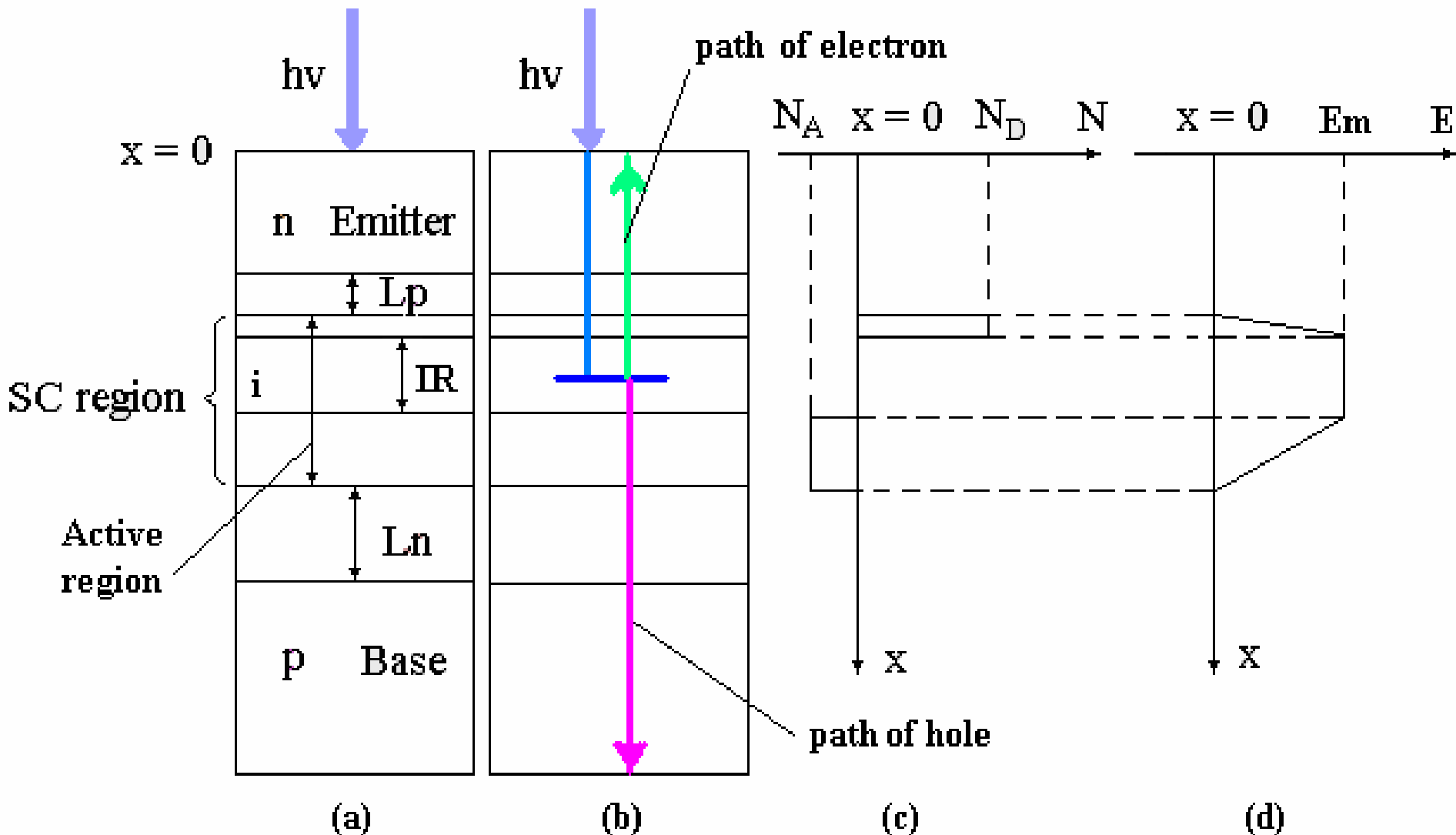
Objectives



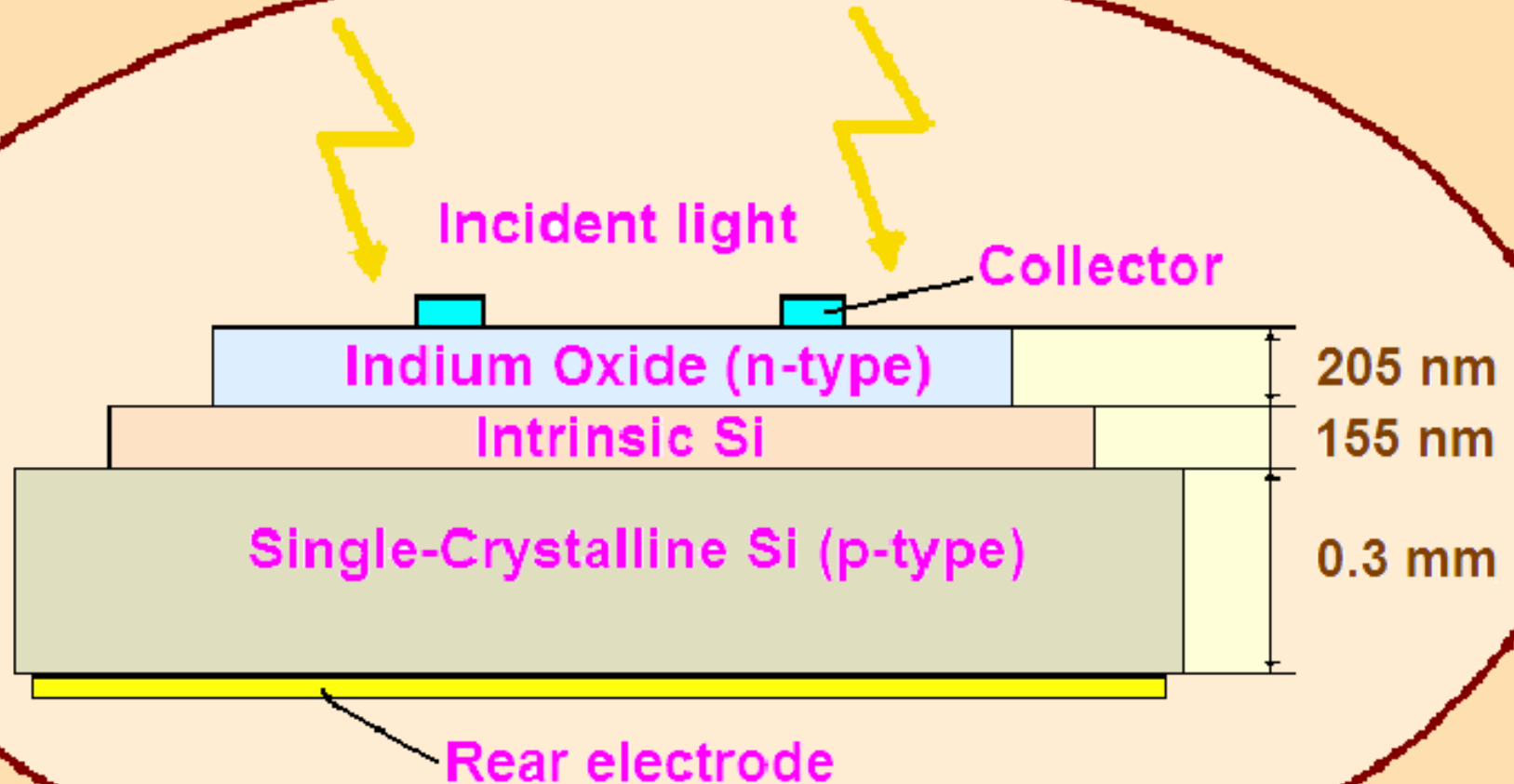
To increase efficiency of semiconductor structure in photo-voltaic conversion we apply widening of the depletion region on the junction using additional intrinsic semiconductor layer.

In this work we describe our experiments with growth of PIN $\text{In}_2\text{O}_3/\text{i-Si}/\text{p-Si}$ structure using the low-pressure plasma sputtering method and after-deposition annealing process: Vacuum-Photo-thermal Processing (VPP).

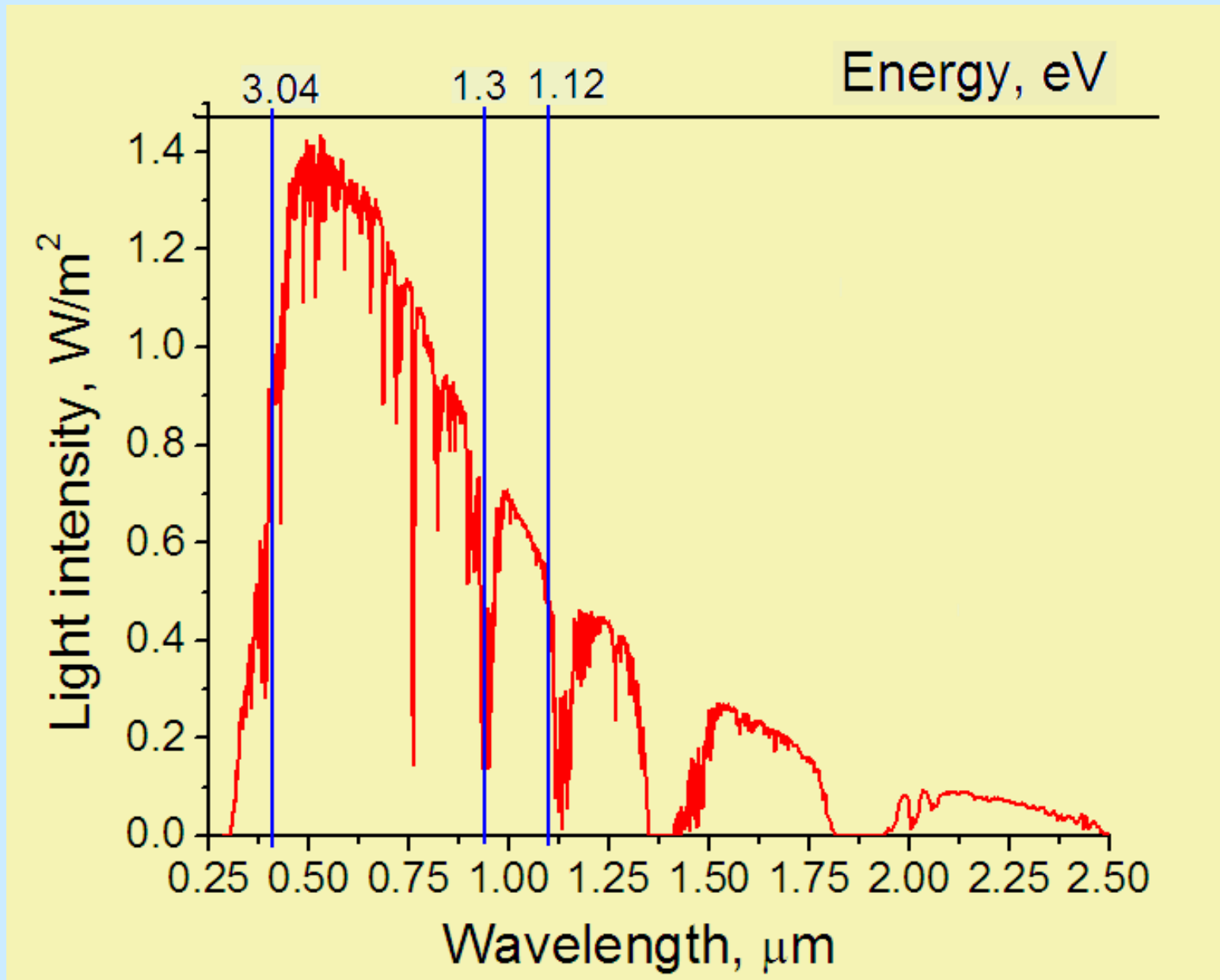
A cross-section of the PIN diode-based PV

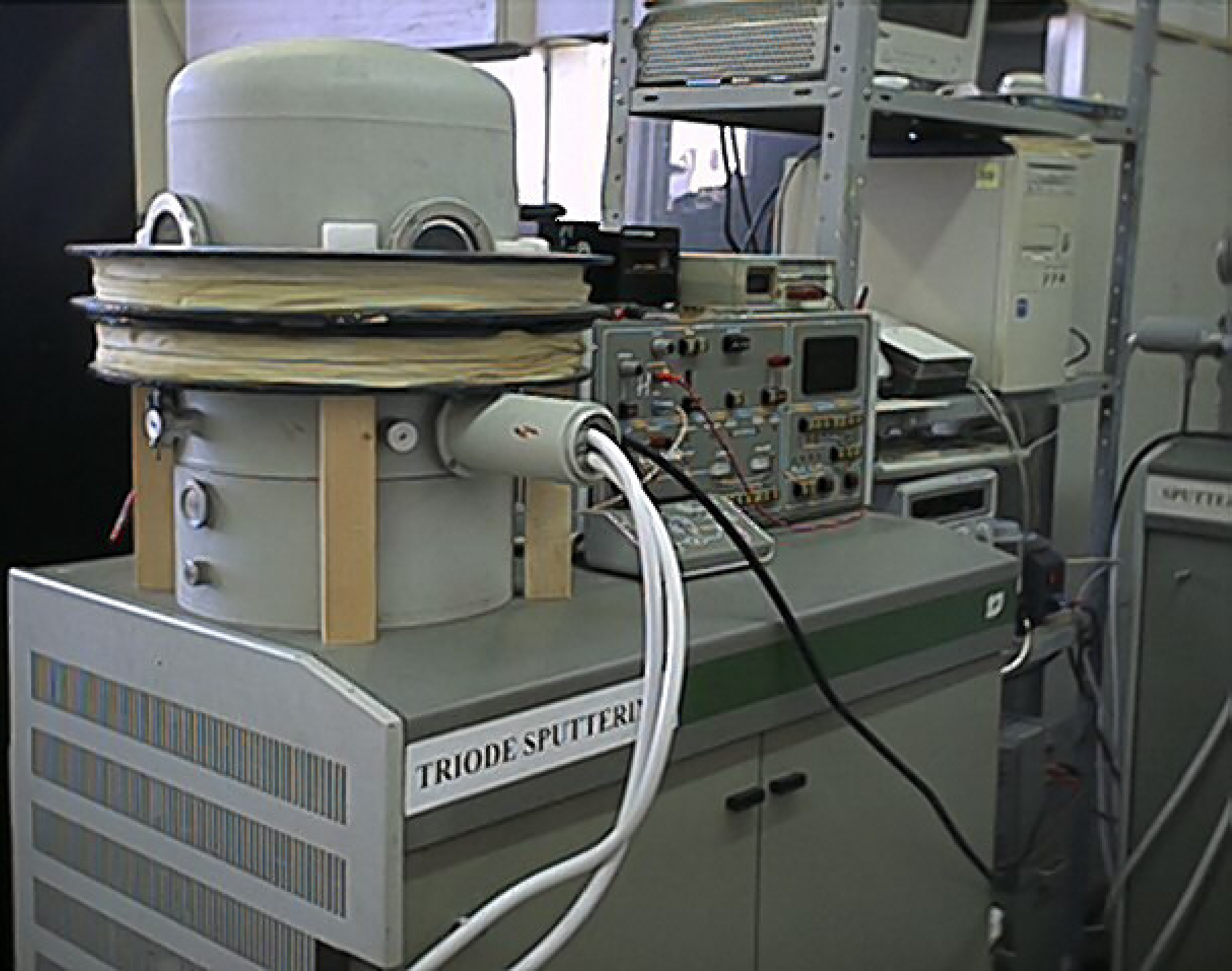


Schematic of the PV structure



Solar light spectral distribution

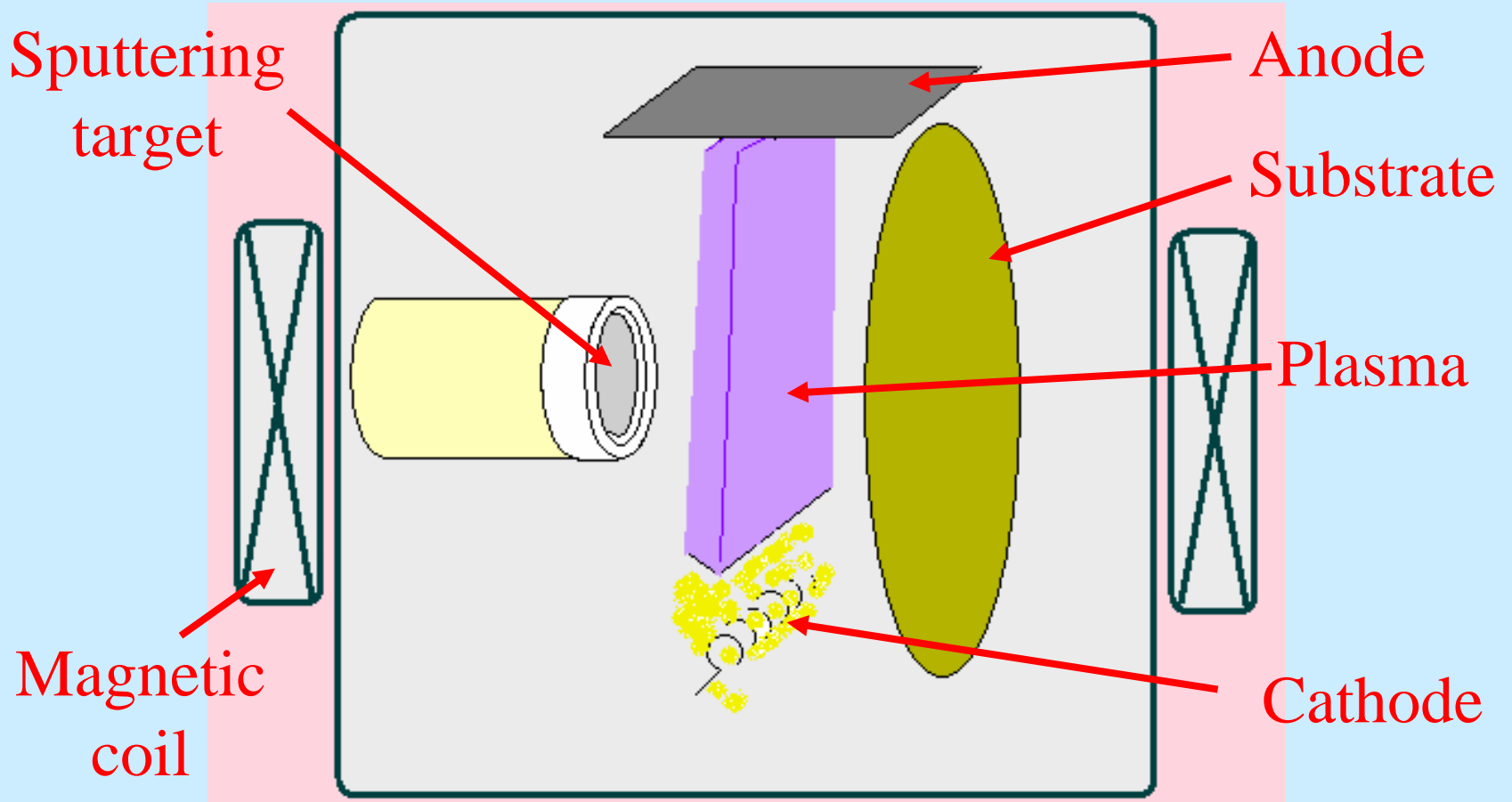




TRIODE SPUTTERING

SPUTTERING

Sheet plasma sputtering method



Schematic diagram of the experiment.

A. Axelevitch et al., 7th IPS
Conference, Israel, 2004

Sputtering Process



Ta anode

Plasma

Substrate

Reference
electrode

Target
holder

G. Golan et al, Plasma Devices and
Operations, 10/4, 2002 (251-261)

Active Technological Parameters

P - Argon pressure: $(5-50) * 10^{-4}$ Torr

T_S - Substrate temperature: 50 - 250°C

I_H - Electromagnet current: 2.5 – 4.5 A

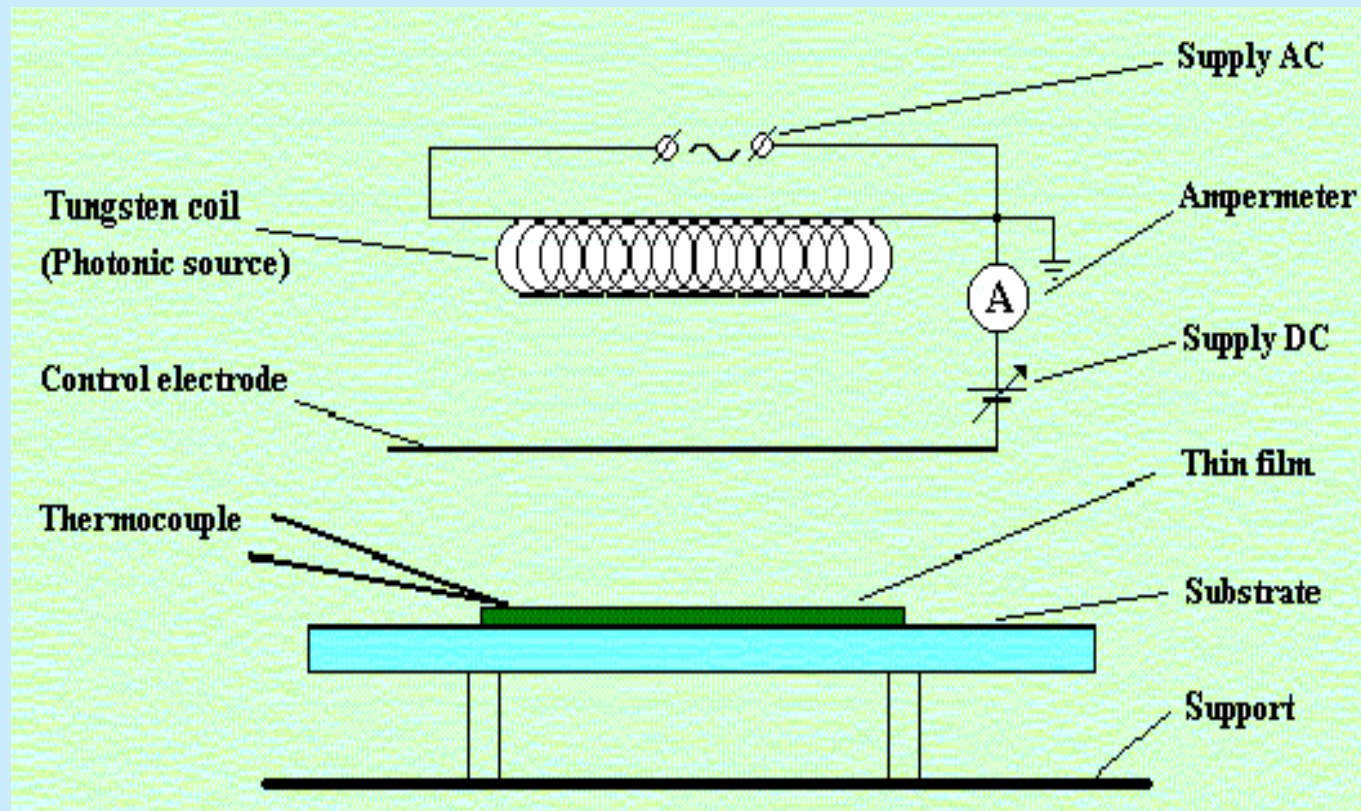
I_C - Cathode current: 17 – 18 A

V_A – Anode voltage: 20 – 40 V

I_A – Discharge current: 0.5 - 4.5 A

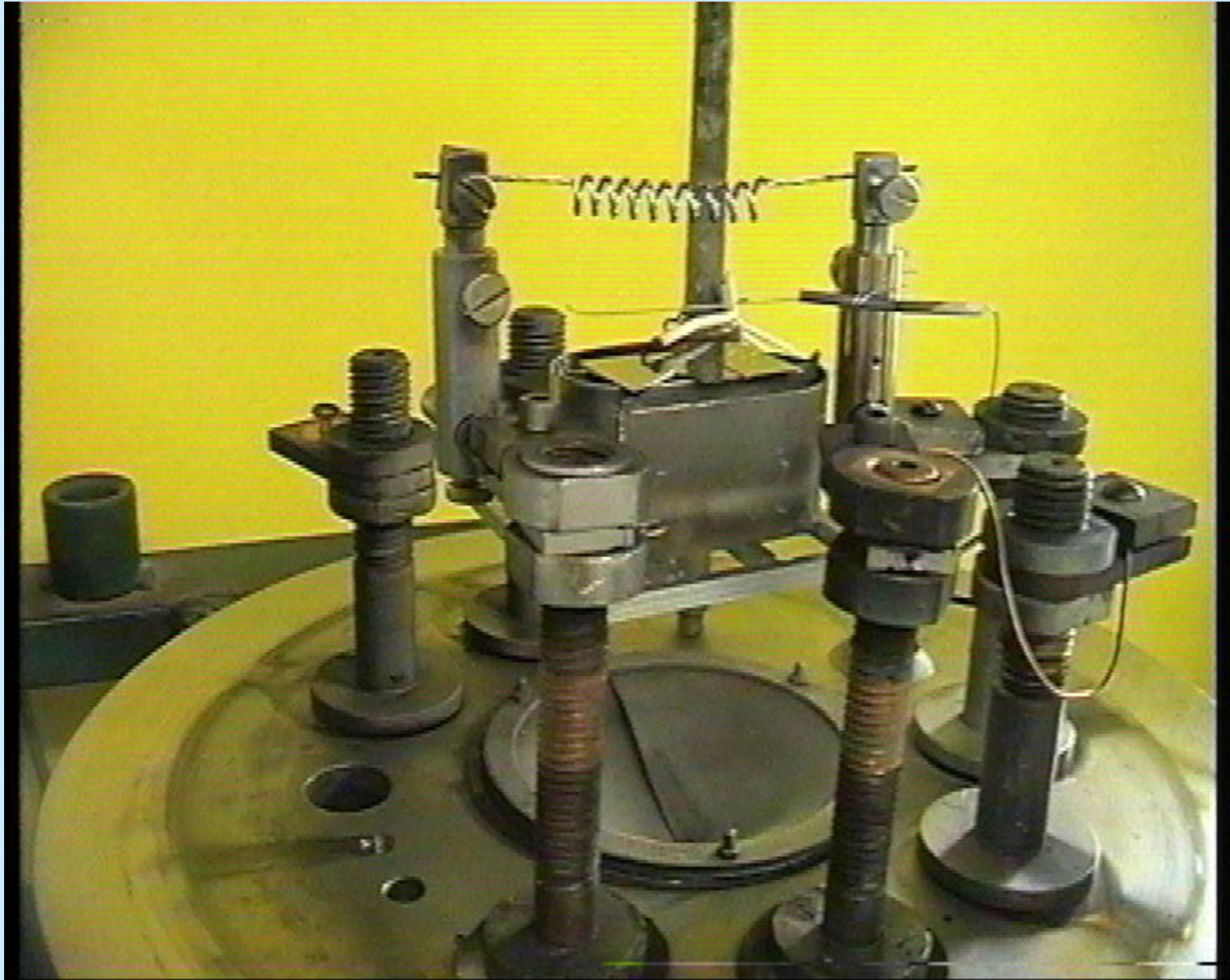
V_T – Sputtering voltage: 0.8 – 2.0 kV

Simultaneous action of high energetic photons and electrons in vacuum has the synergetic effect and significantly modify electron properties of the affected material, its surface structure and internal composition.

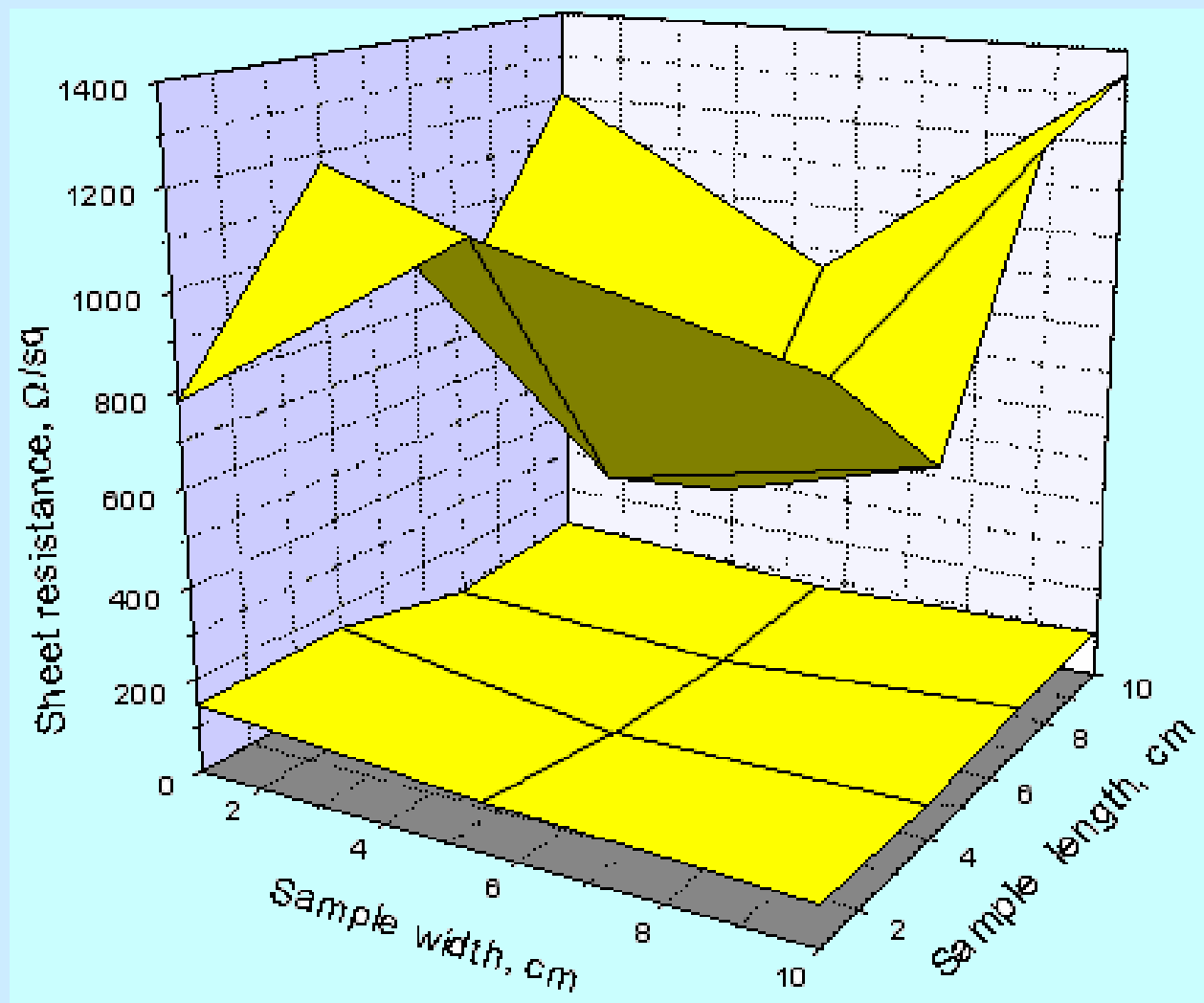


G. Golan, A. Axelevitch, Microelectronics Journal 37, 2006 (459-473)

Vacuum Photo-thermal Processing (VPP)

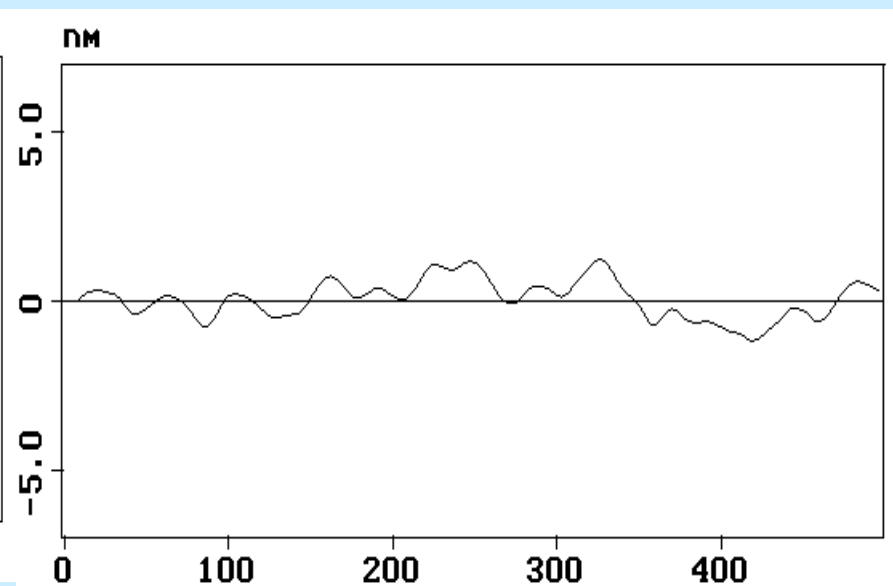
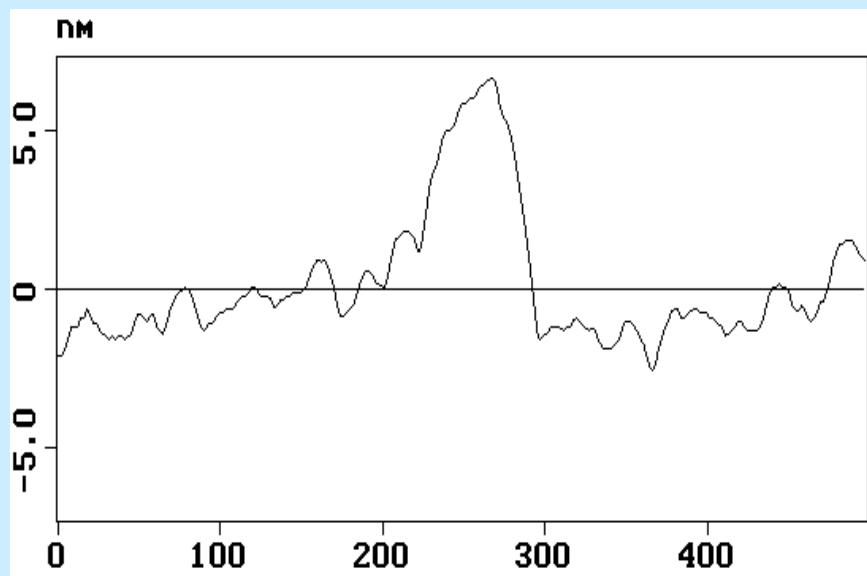
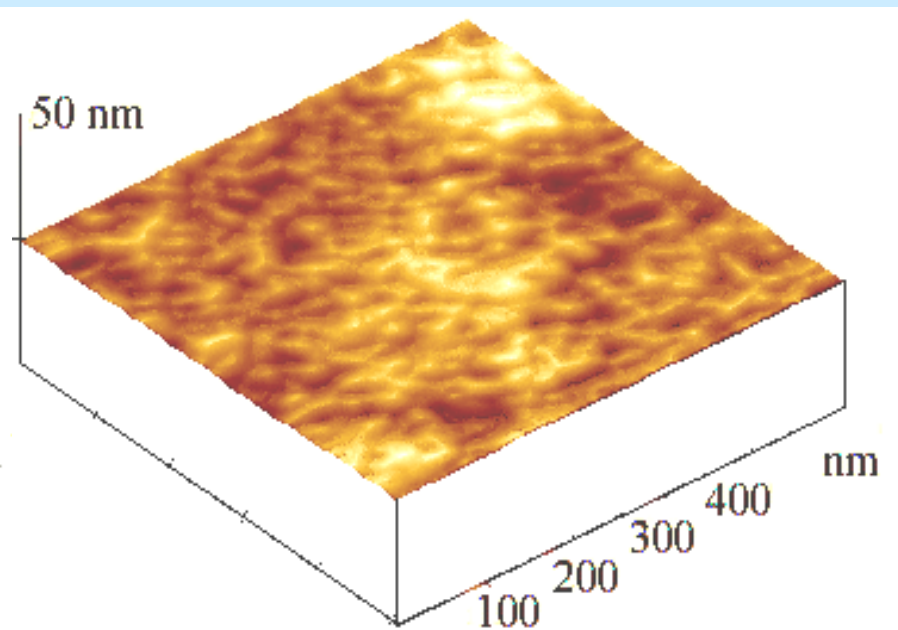
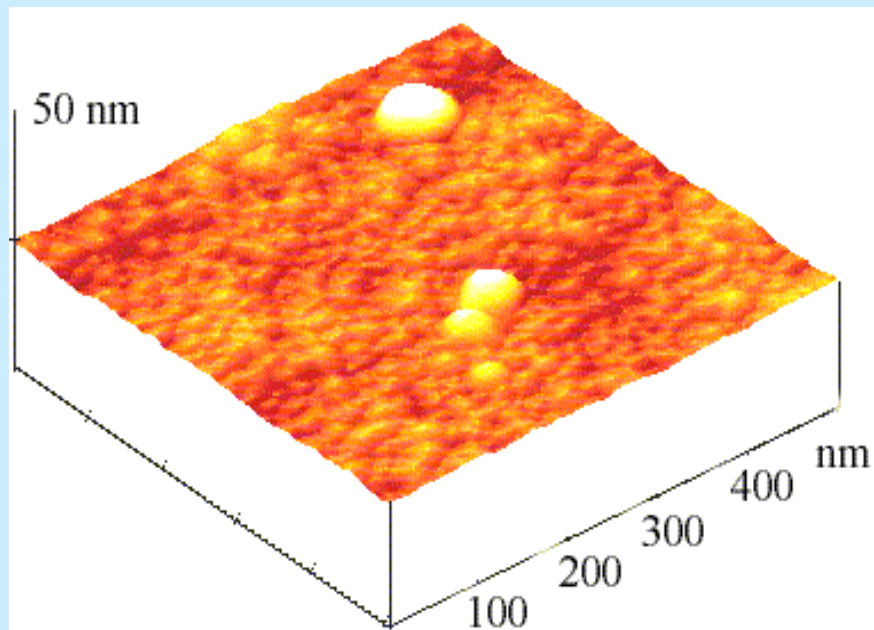


Homogenization of Coating Parameters



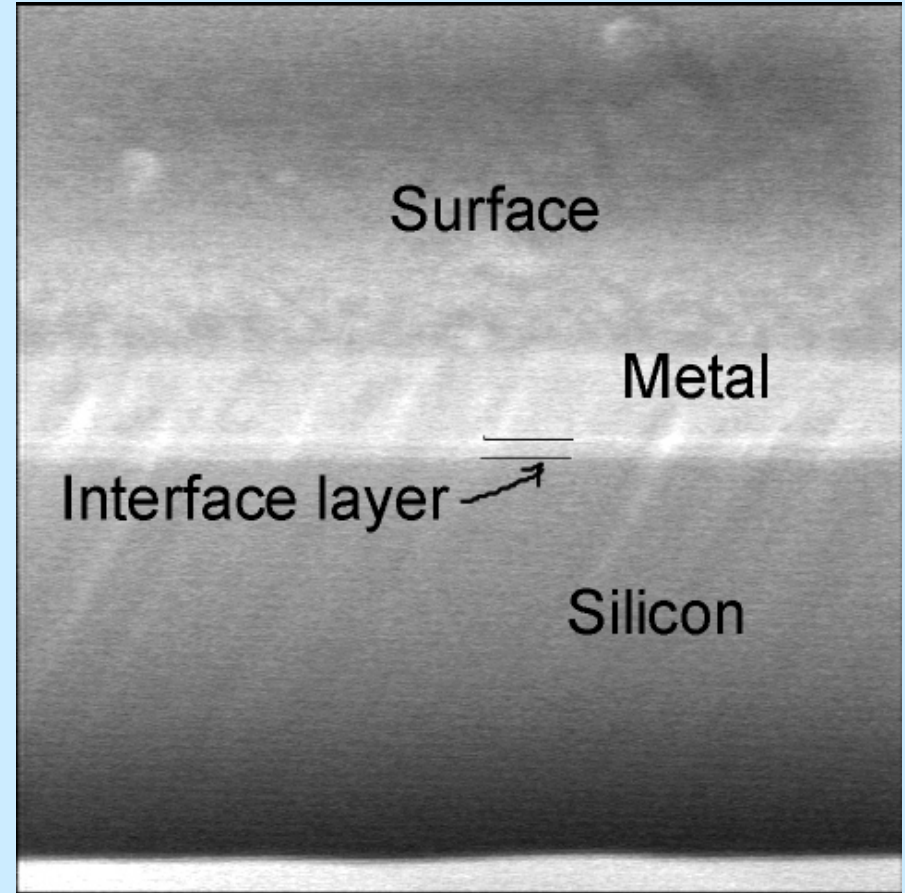
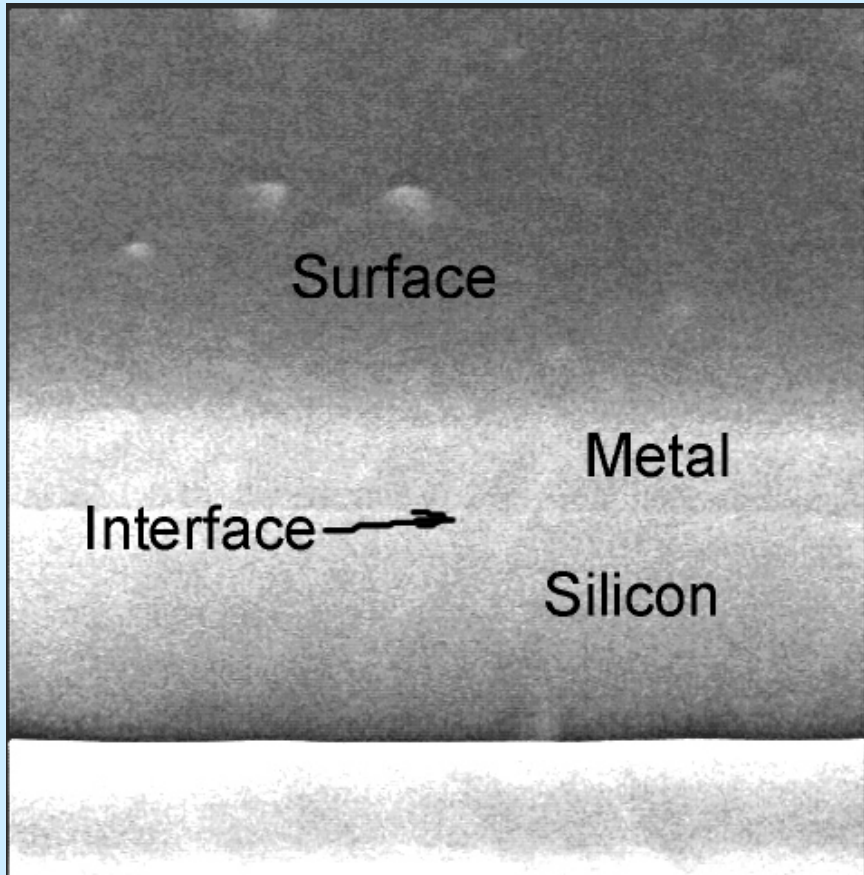
In_2O_3 thin film sheet resistance before (upper) and after (lower) the VPP

G. Golan et al, J. of Optoelectronics and Advanced Mat., 1/4, 1999 (69-808)



VPP treatment of metal-silicon structure

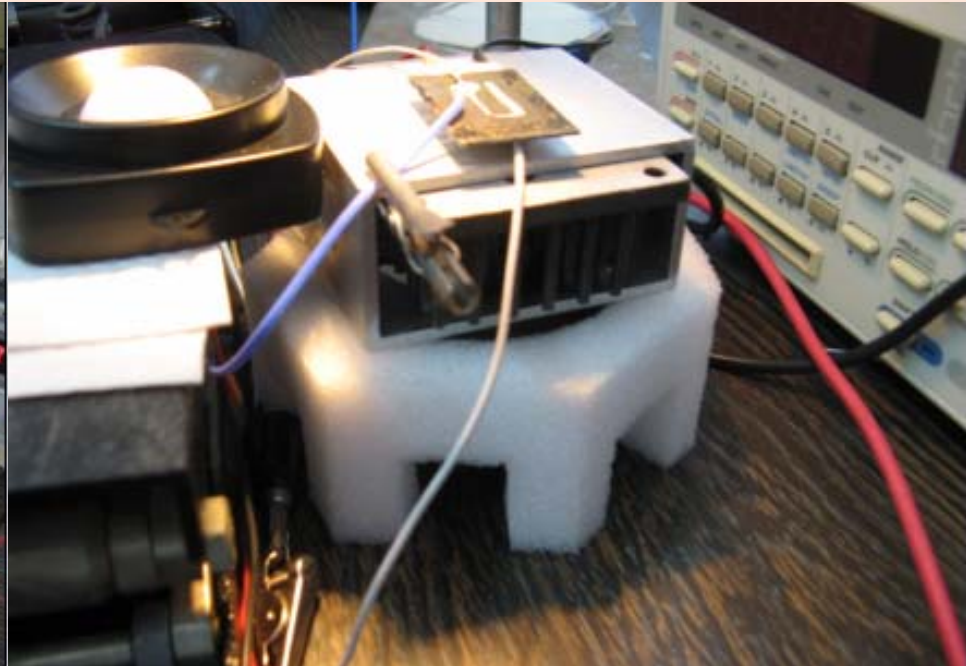
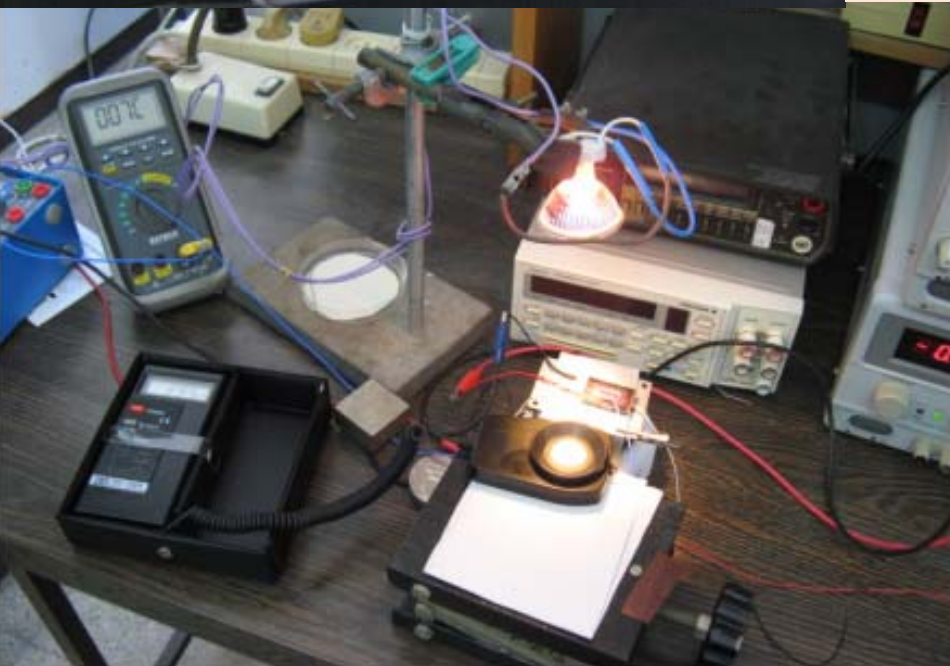
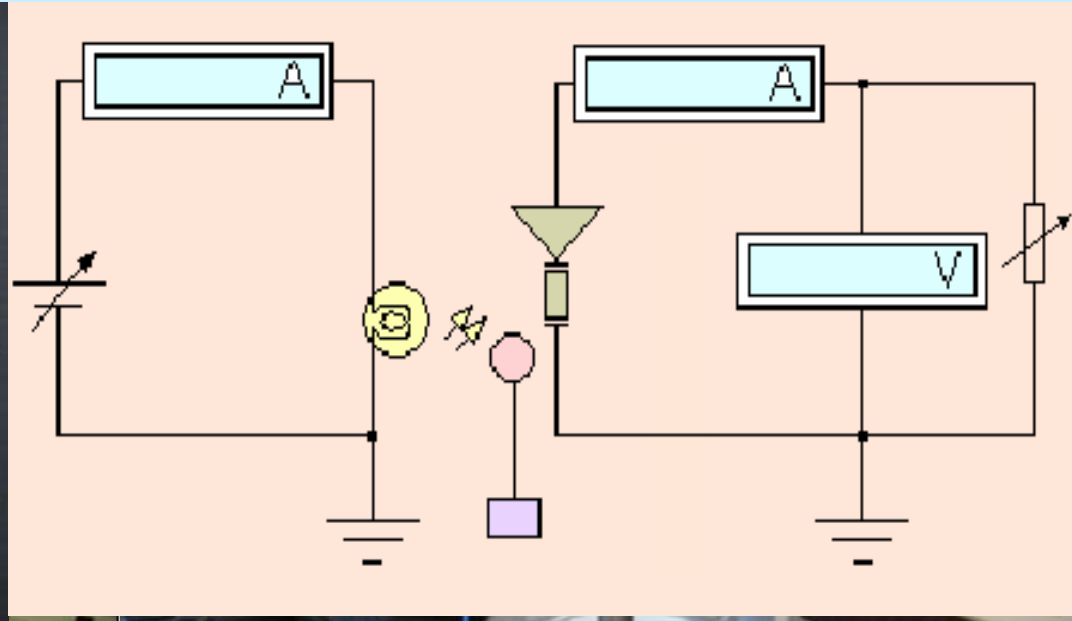
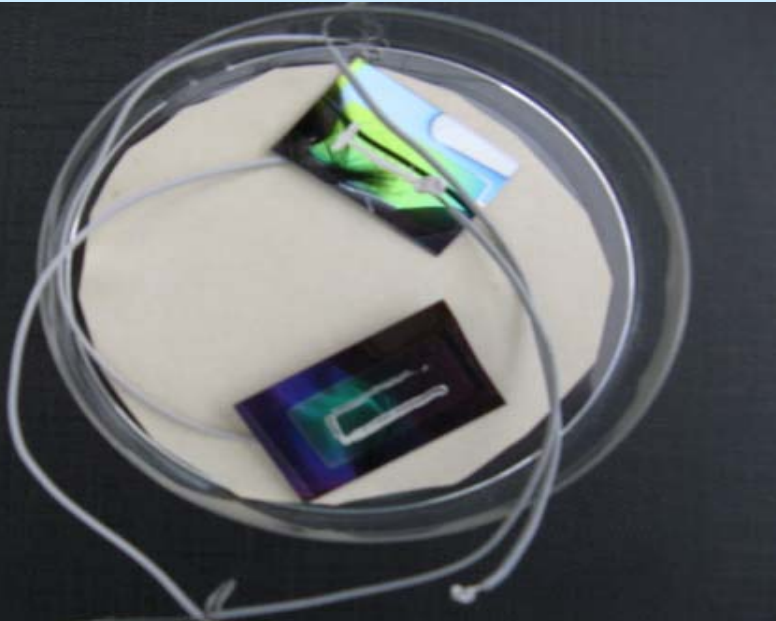
Before VPP



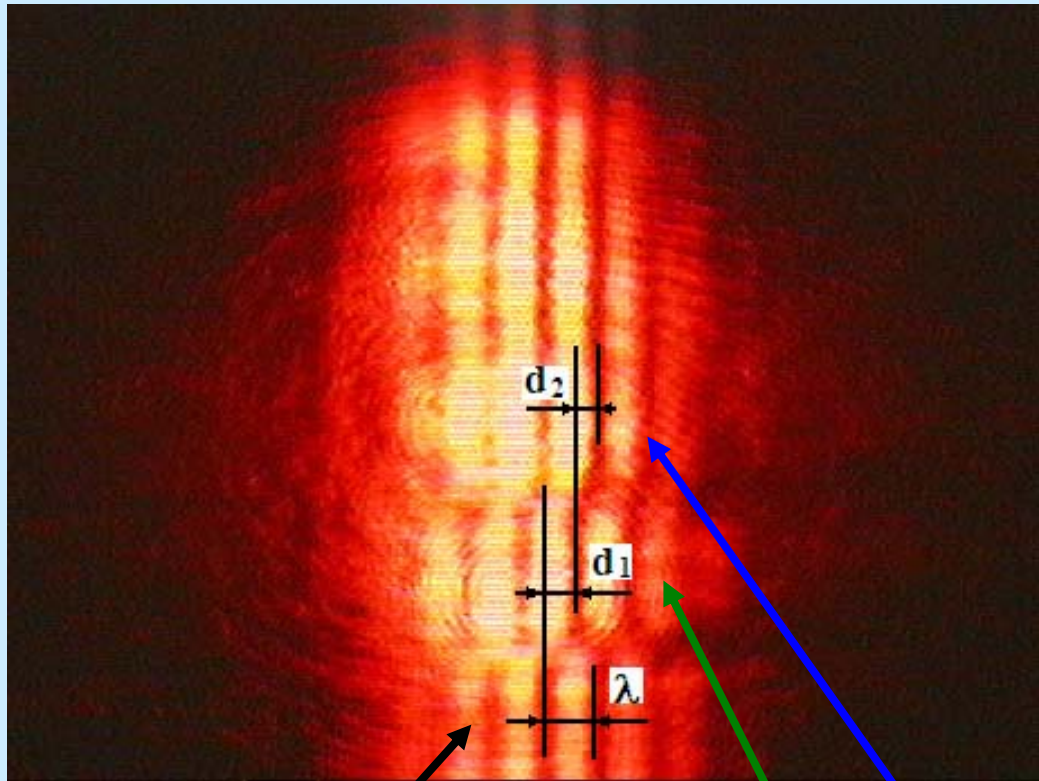
After VPP

G. Golan et al, Proc. of MIEL 2004, Nish, Serbia and Montenegro, 2004 (425-428)

Testing of the PV structures



Interferential picture of investigated multilayer system $\text{In}_2\text{O}_3/\text{i-Si}/\text{p-Si}$

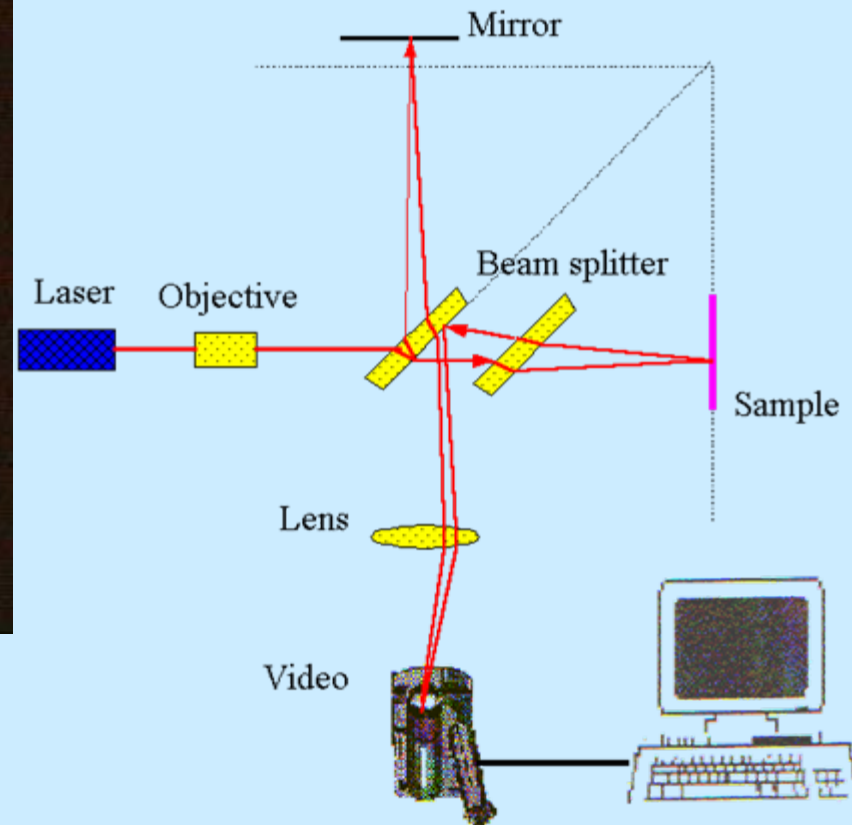


Upper In_2O_3 emitter coating

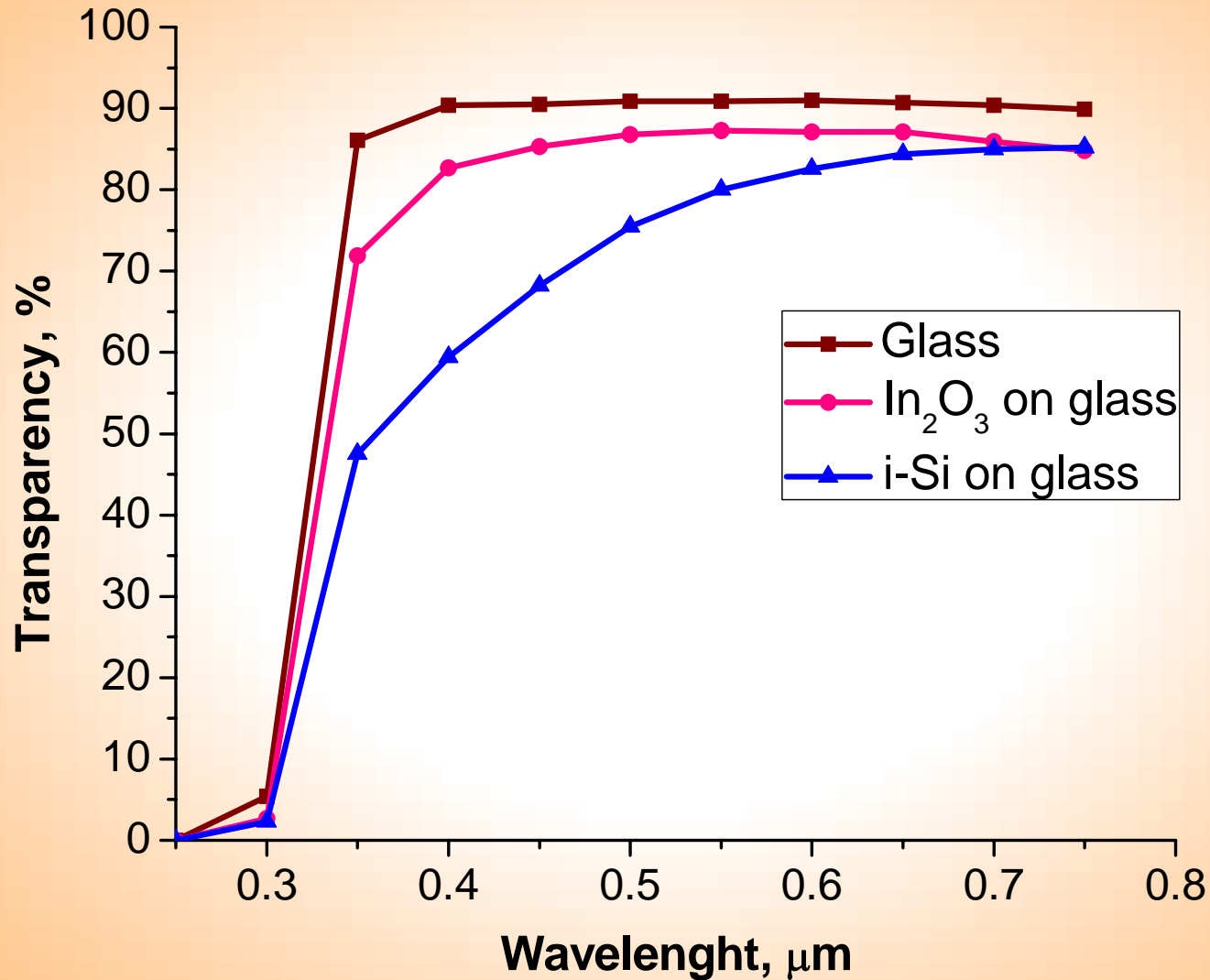
Thin intrinsic Si layer

Mono-crystalline p-Si substrate

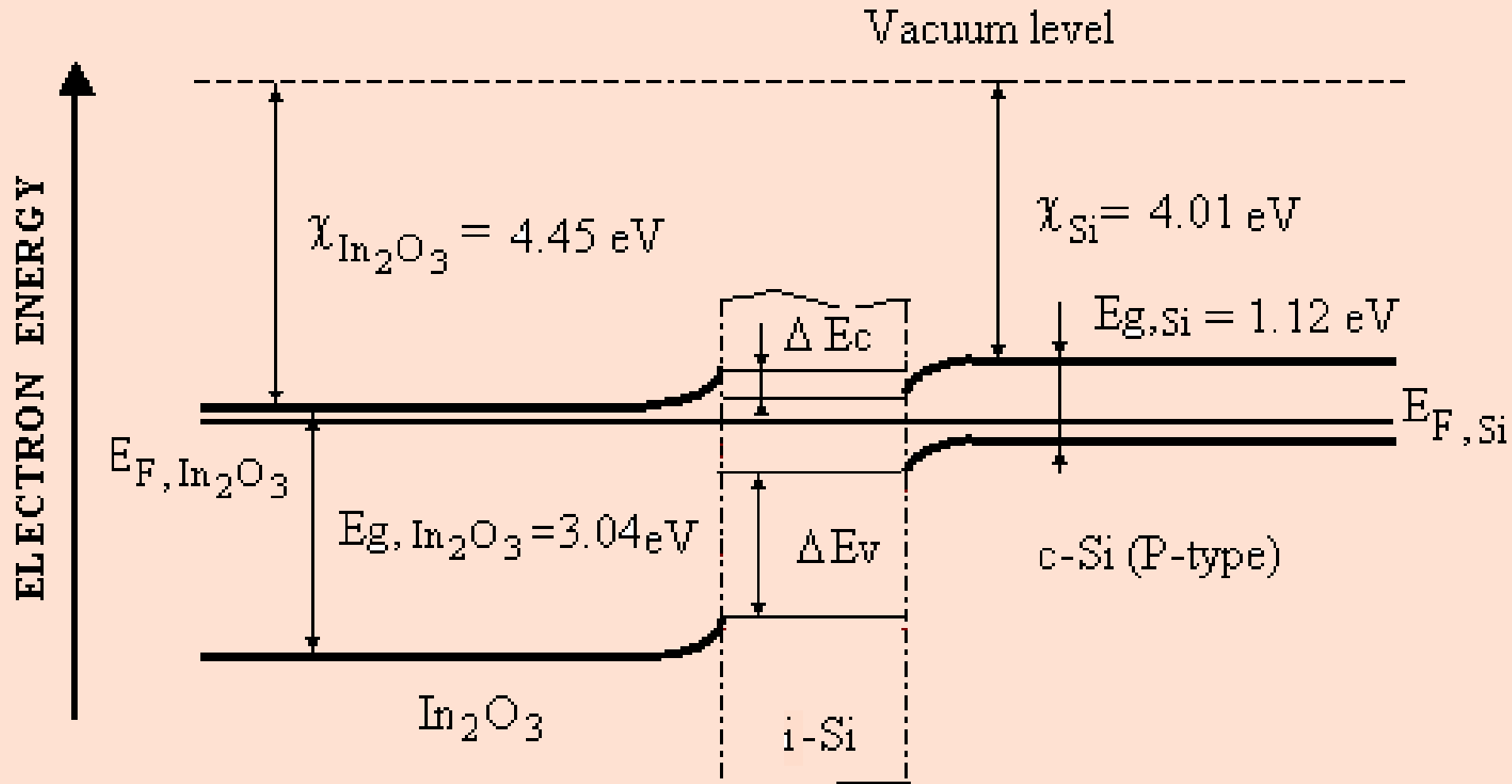
Thickness contact less measurement scheme



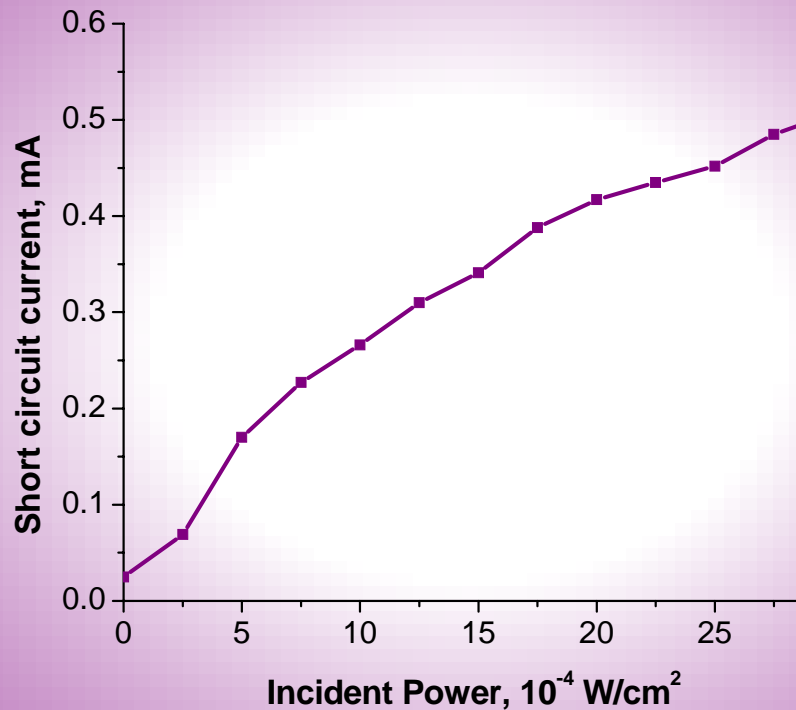
Transparency of deposited films



Energetic diagram for PV cell

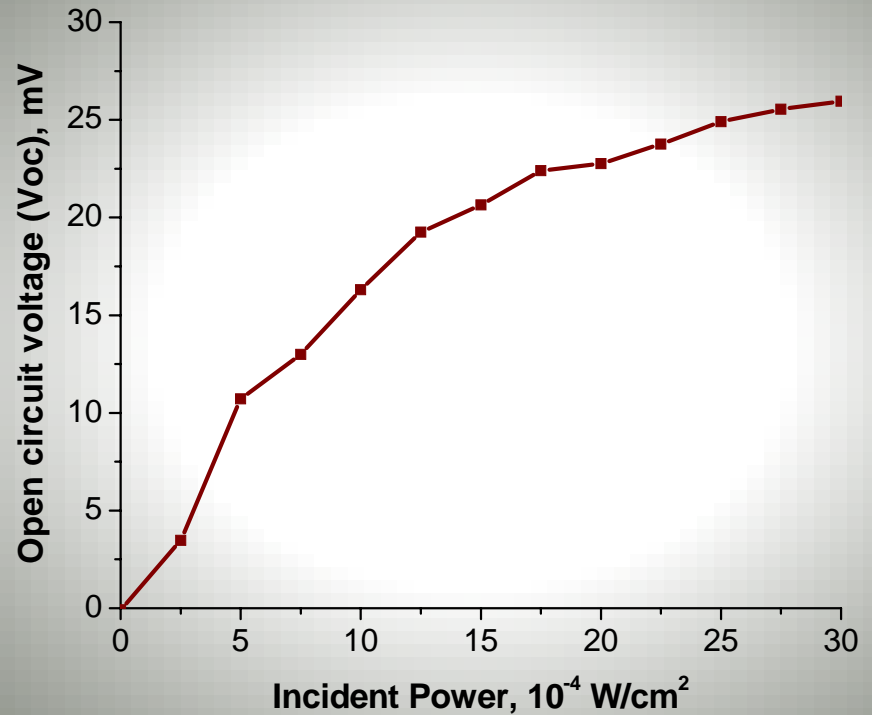


Basic measured parameters

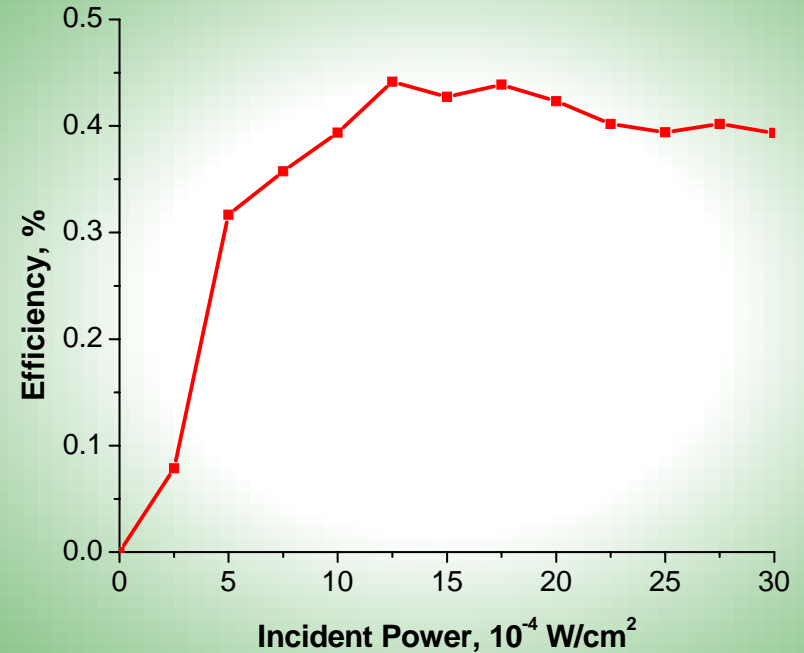
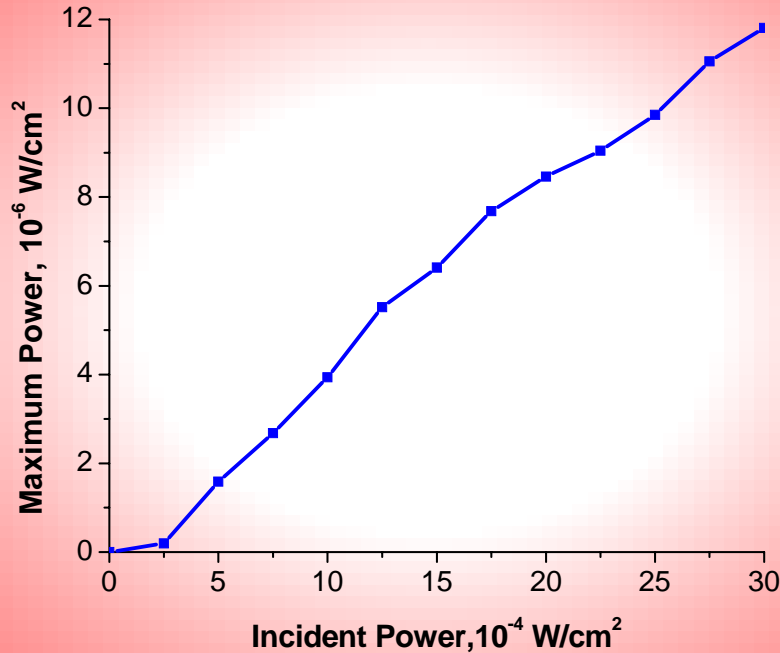


Short circuit current

Open circuit voltage



Basic calculated parameters



Maximum Power, $P_m = I_m * V_m$

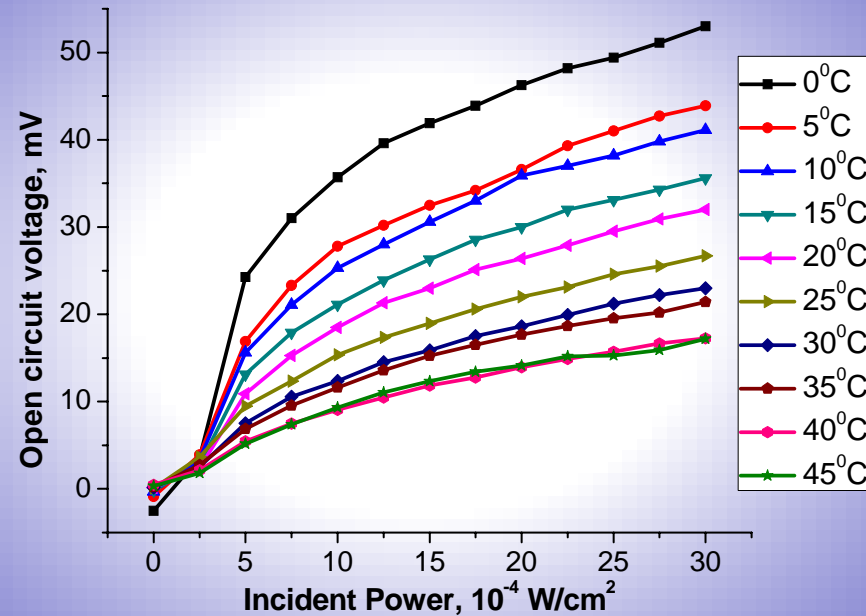
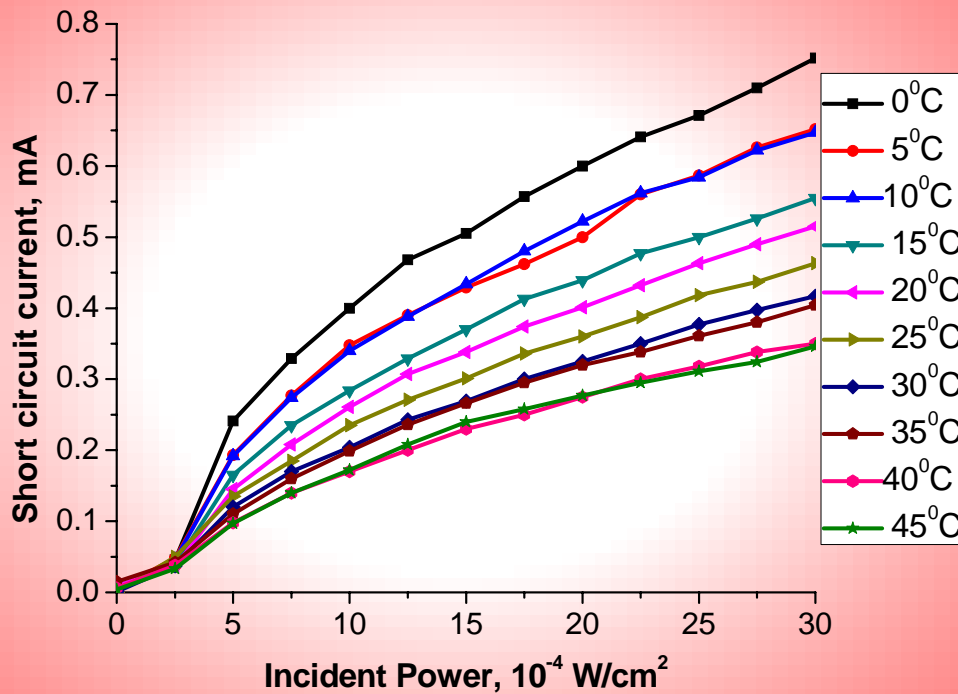
$$I_m = I_s \left(e^{\frac{V_m}{V_t}} - 1 \right) - I_L$$

Efficiency, $\eta = P_m / P_{in}$

$$V_m \cong V_{oc} - V_t \ln \left(\frac{V_m}{V_t} + 1 \right)$$

Temperature influence on basic PV parameters

Short circuit current



Open circuit voltage

Conclusions

Optical and electrical properties of the deposited films were investigated using laboratory equipment. It was found that the bandgap of the intrinsic silicon layer is equal to 1.3 eV and bandgap of the emitter layer (In_2O_3) equals to 3.04 eV. Resistivity of the obtained emitter layer was equal to $5.24 \cdot 10^{-3} \Omega \cdot \text{cm}$. Efficiency of the photovoltaic structures was no more 0.2 %. The prepared samples show feasibility to grow photovoltaic devices using the sheet plasma sputtering method.