

Extremely Thin Absorber Solar Cells: EU Project Overview

Status quo and perspectives

A European Research Project
(HPRN-CT-2000-00141)



Outline

- **Energy Research Center of the Netherlands**
- **ETA solar cells: A PV technology for the future ?**
 - Motivation
 - Materials and methods
 - Interface Design
 - Comparison of different systems
- **Summary (status quo)**
- **Future Research Perspectives**



Energy Research Center of the Netherlands

Bridge between academic research and commercial application



- Largest independent energy research center in NL (600 co-workers)
- R&D for/with private enterprises and governmental institutions, (national + international)
- Core Research:
Sustainability in energy generation and use



Research Priority Areas at ECN



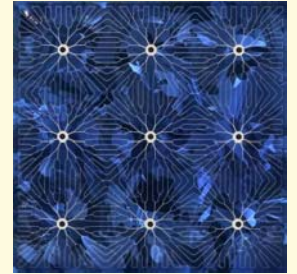
- **Solar Energy**
- **Biomass**
- **Windenergy**
- **Fuel Cells**
- **Clean Fossil Fuels**
- **Energy Efficiency in Industry**
- **Building Integration of Renewable Energies**
- **Policy Studies**



ECN Solar Energy

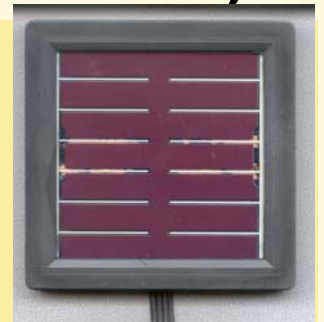
Conventional and Advanced Silicon

- New contact and module concepts
- Ribbon grown Si



Thin Film Solar Cells

- Thin Film Si (low T deposition on substrates)
- Chalcopyrite
- Dye Sensitized Solar Cells (Electrolyte and Solid State)
- Polymer- und Hybrid Solar Cells
- **ETA Solar Cells**



EU Network Project : ETA Solar Cells

Project Partners:

Energy Research Center of the Netherlands (ECN)

Hahn Meitner Institute (HMI)

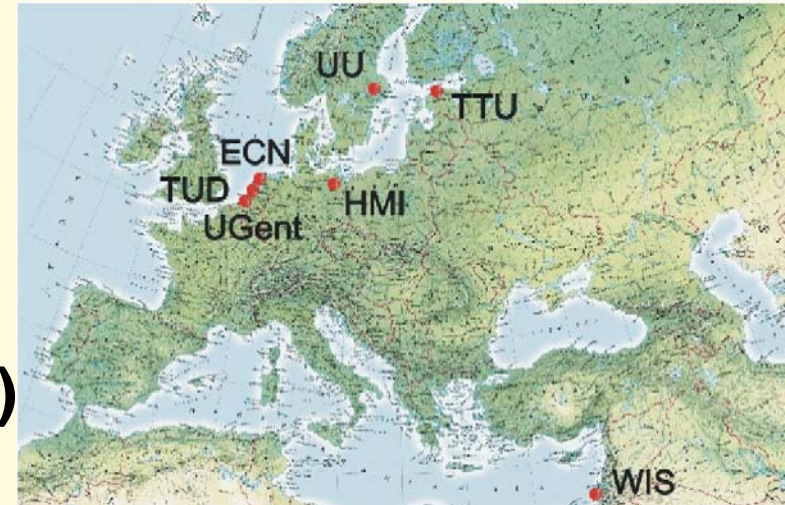
Rijksuniversiteit Gent (UGent)

Tallinn Technical University (TTU)

Technical University Delft (TUD)

Uppsala University (UU)

Weizmann Institute of Science (WIS)



Project Coordinator: Dr. Jeannette Wienke (ECN)



Motivation for the project

Question:

Is it possible to cope with absorber materials of low electronic quality (defects) ?

Implications:

Short charge carrier lifetimes

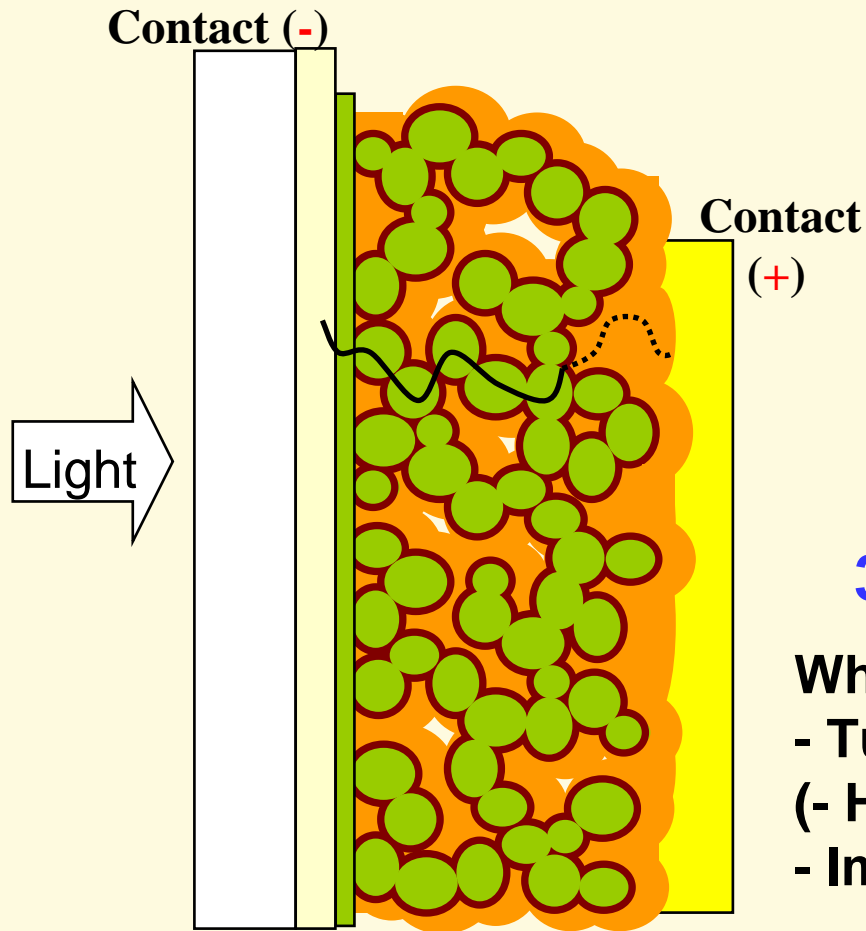
High (bulk) recombination probability

Proposed solution:

Short distances to charge separating interface



Concept : Extremely Thin Absorbers (~ 2 - 50 nm)



■ Transparent n- type

■ Inorg. absorber or mol. dye

■ Transparent p- type

3 component (nano)composite

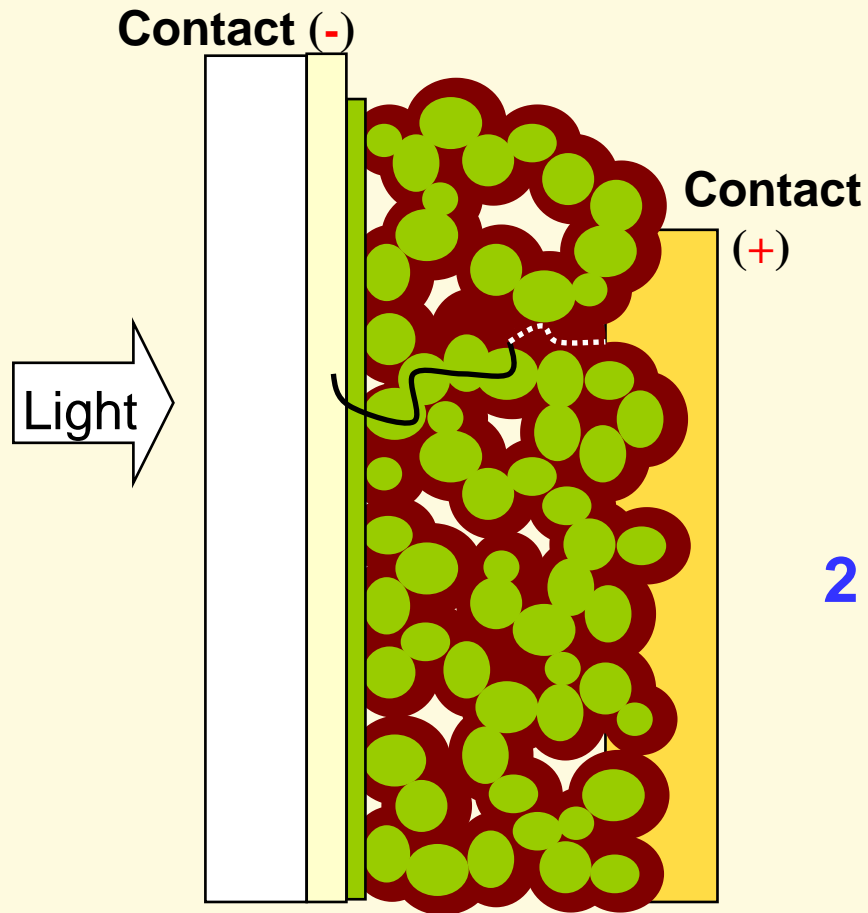
Why inorganic absorbers ?

- Tunability of E_g
- (- Higher absorption)
- Impact ionization

Könenkamp et. al., Appl. Phys. Lett. **75** (1999) 692
O'Regan, Schwartz, Chem. Mater., **7** (1995) 1349



Concept : Extremely Thin Absorbers (~ 2 - 50 nm)



■ Transparent, n- type

■ p - Absorber

2 component (nano)composite

Challenges

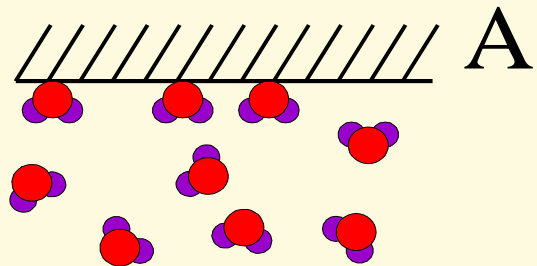
- **Deposition techniques** for thin (absorber) layers inside porous films
- **Materials:** n-type, p-type, absorber (band alignment, structural, defect chemistry)
- **Interface:** Recombination
- **Modelling and characterization** (new device concept, complex geometry)



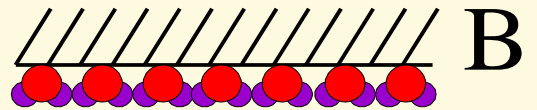
Deposition Techniques

- **ALD: Atomic Layer Deposition**
(CuInS_2 , Al_2O_3 , In_2S_3) **M. Nanu - TUD**
- **CBD: Chemical bath deposition**
(CdS , CdSe , $\text{In}(\text{OH})_x\text{S}_y$) **O. Niitsoo - WIS**
- **ILGAR: Ion Layer Gas Reaction**
(Al_2O_3 , CuInS_2) **H. Muffler - HMI**
- **Spray pyrolysis**
(CuInS_2) **A. Katerski TTU**
- **Solution casting (CuSCN)** **B. O'Regan - ECN**
- **Electrodeposition (CdTe , CdHgTe)** **A. Belaidi - HMI**

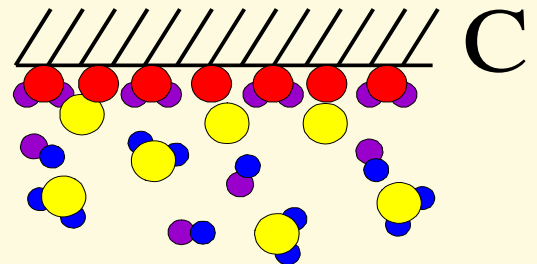
Atomic Layer Deposition (TU Delft)



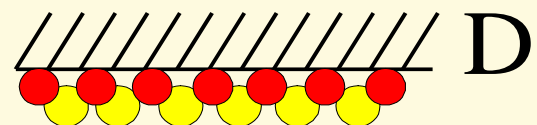
Adsorption Compound 1 (CuCl, InCl₃)



Monolayer Formation (compound 1)

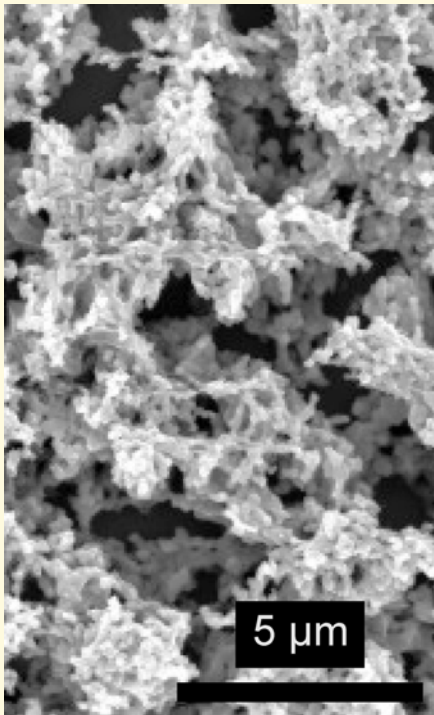


Surface Reaction with compound 2 (H₂S)

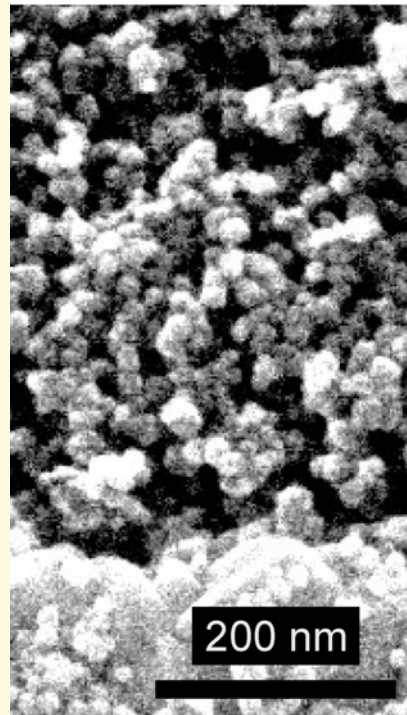


Transparent n-type materials

TiO₂ films with different microstructures/electronic properties



Micron-sized pores in a spray-pyrolyzed TiO₂ film



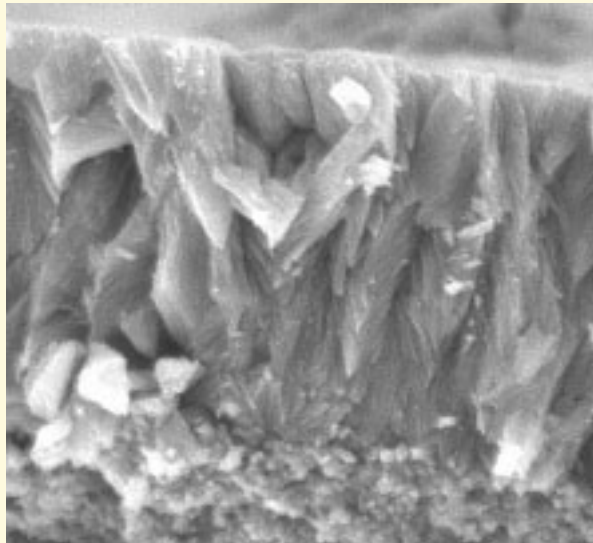
Nano-sized pores in a screen-printed TiO₂ film

Alternative materials like ZnO, SnO₂ under development

- electron mobility*
- band alignment*
- defect chemistry*

Transparent p-type materials

CuSCN, CuI, (CuAlO₂)



1 μm thick CuSCN on top of a TiO₂ layer

- **Mandatory in dye sensitized solar cells**
- **Not always mandatory in ETA solar cells**

B. O'Regan - ECN



Absorbers

Inorganic binary compounds (E_{gap}):

PbS-q.s. (~1.1 eV)

CdTe (1.45 eV)

CdSe (1.8 eV)

Inorganic ternary compound (E_{gap}):

CuInS₂ (1.5 eV)

Molecular metal-organic („ E_{gap} “):

Ru(II)L₂(NCS)₂ “N3”-dye (~ 1.7 eV)

 = *best inorganic absorber of the project*



Characterization Methods

Structural : SEM, TEM, BET, Raman, XPS

Crystallogr. : XRD

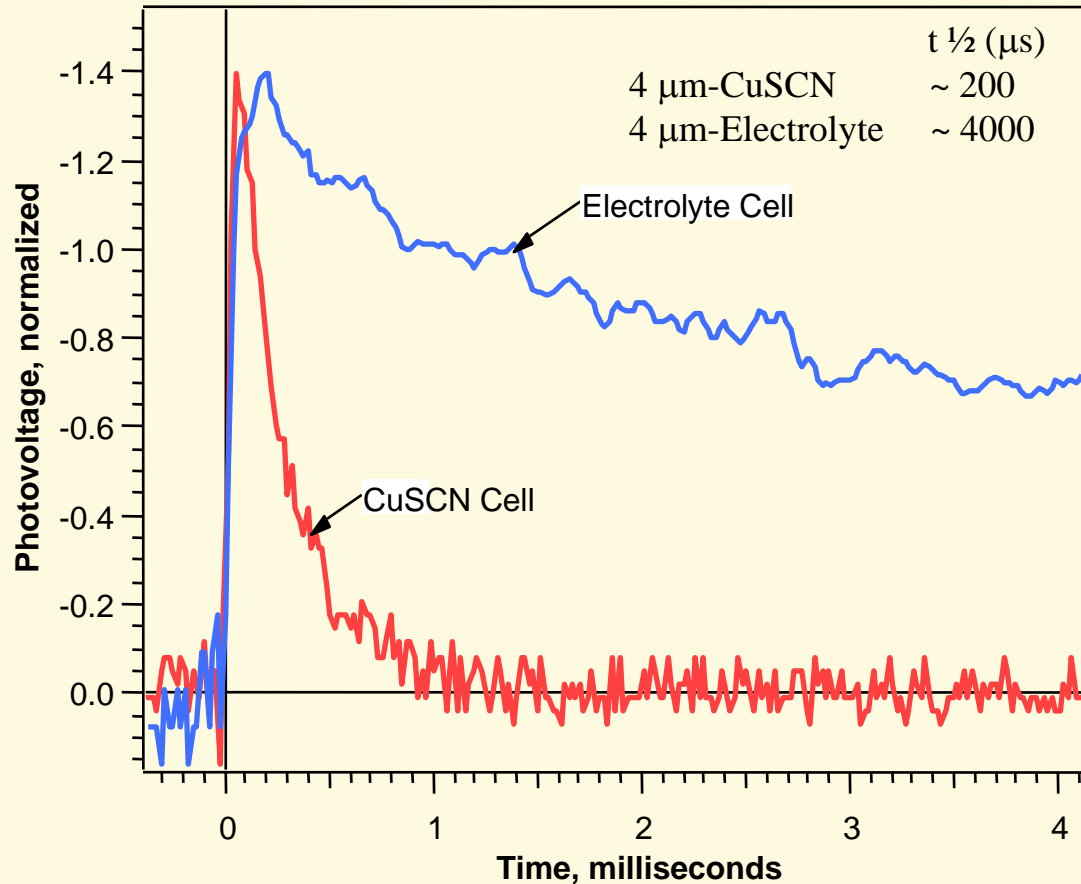
**Electrical : Current-voltage, IMPS, IMVS,
Surface Photovoltage,
Transient Measurements (I,V)**

Optoelectronic : DLTS, PL



Characterization I: Voltage Transient Measurements

Recombination dynamics: Example: $\text{TiO}_2/\text{Dye}/\text{Electrolyte}$ (CuSCN)



**Faster recombination in
CuSCN based dye cells**

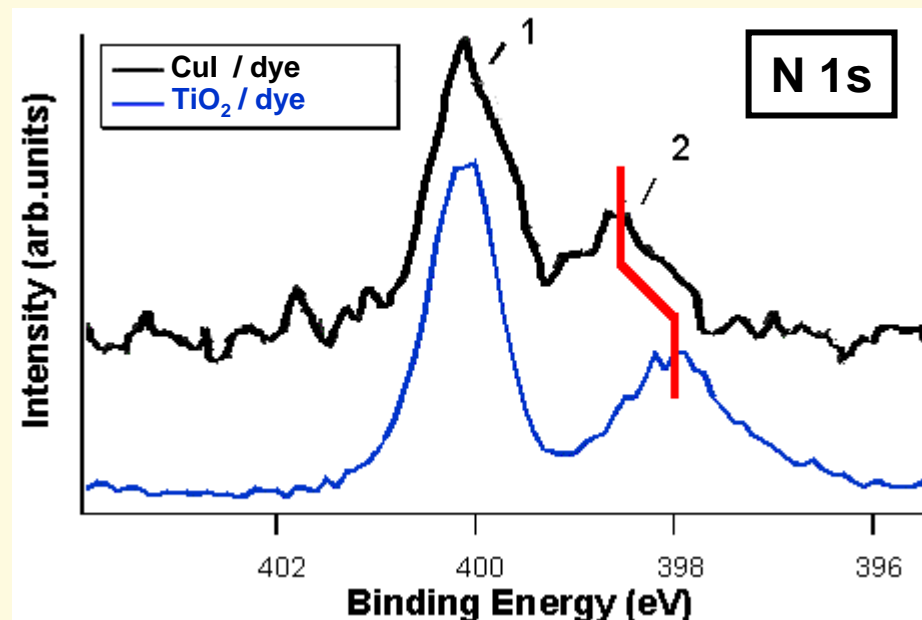
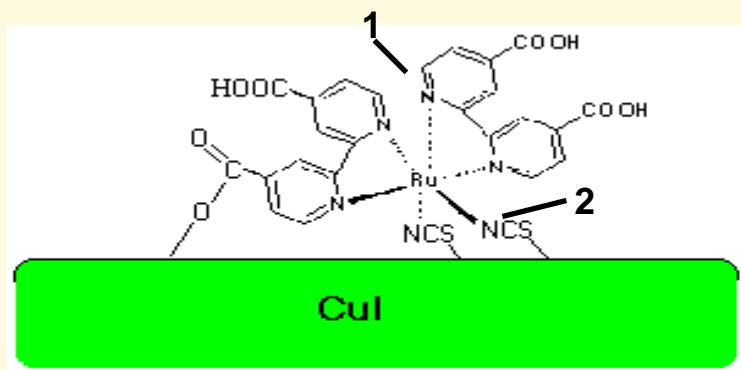
B. O'Regan - ECN

Background Illumination: 1 sun
Flash Illumination: $\sim 10\%$



Characterization II: XPS - Interface structure

CuI/Dye Interface

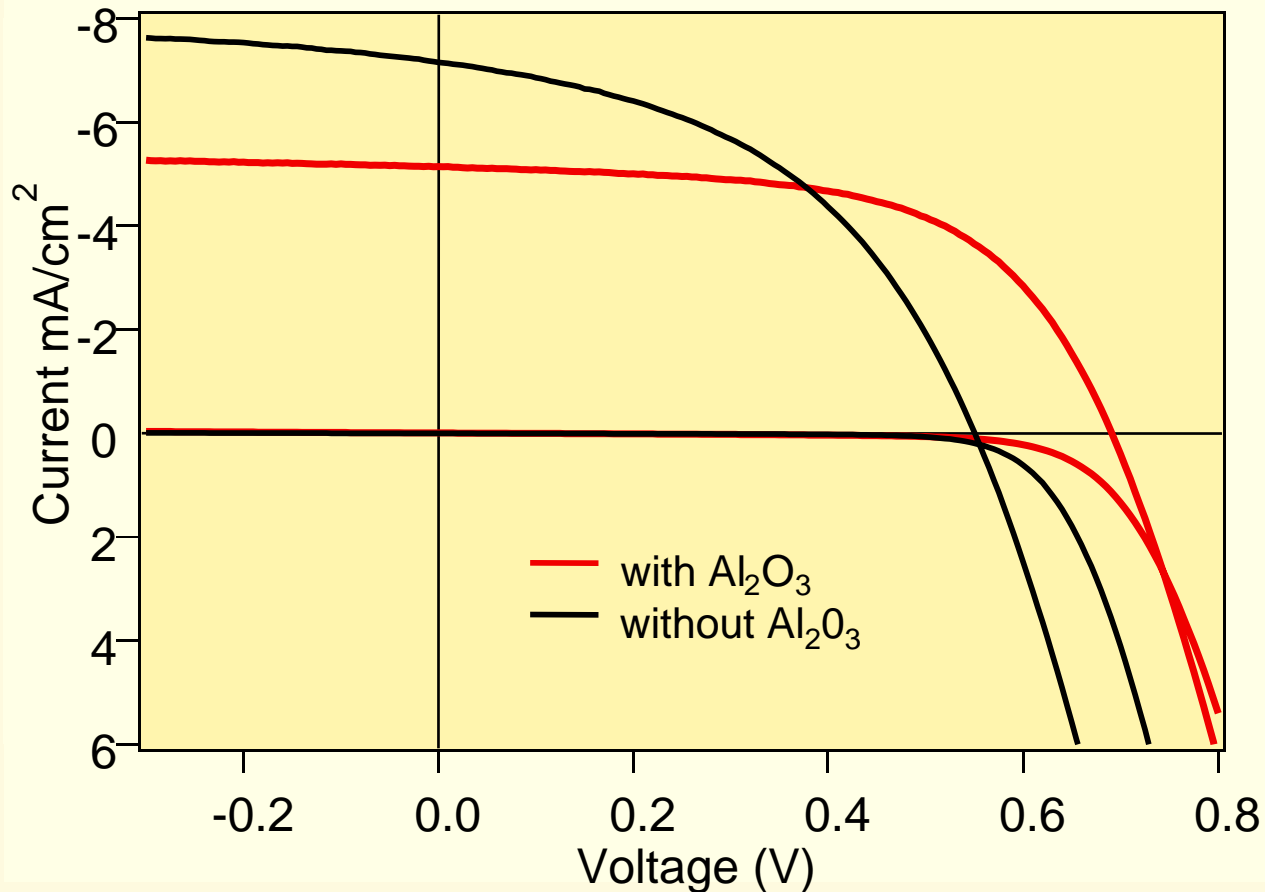


B. Mahrov - UU

Evidence for change of the chemical environment of the N3-dye molecule at the CuI surface

Interface II: Modification by additional layers

Example: TiO_2 (por) / Al_2O_3 / Dye / CuSCN



J_{sc} : 5.2 mA/cm²

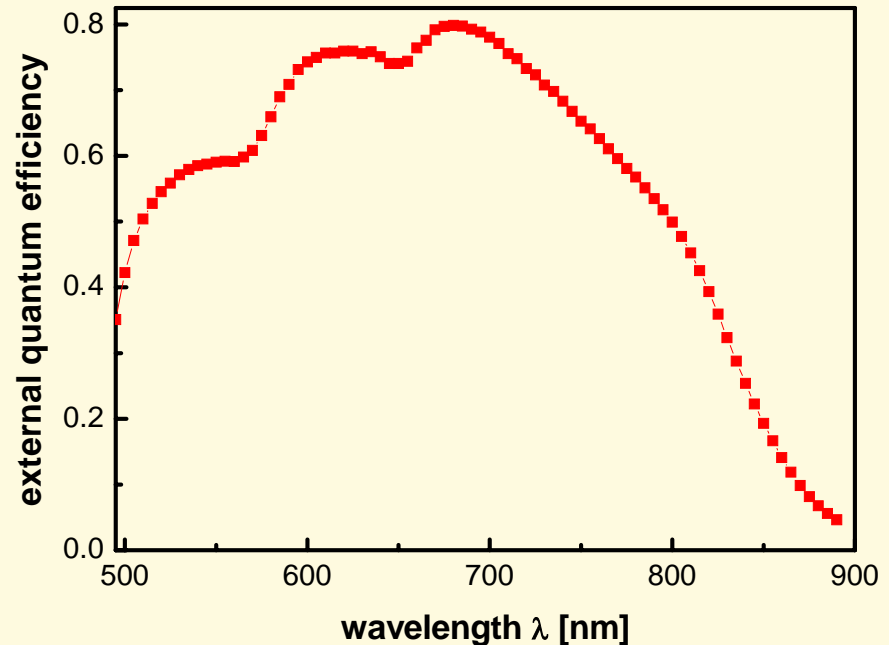
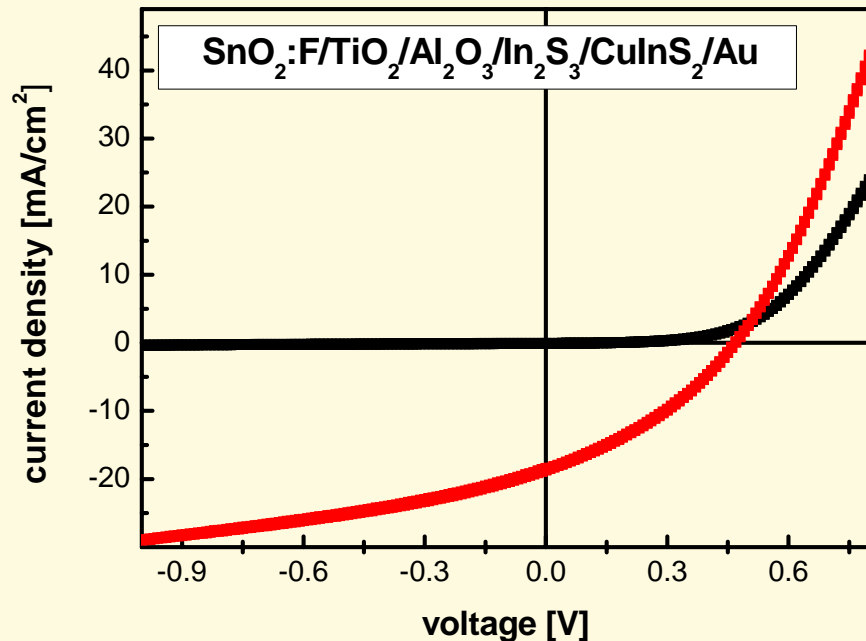
V_{oc} : 690 mV

ff : 59 %

η : 2.1 %

Interface III:

2 interface layers (Al_2O_3 & In_2S_3)
 \Rightarrow best cell with inorg. absorber



$V_{\text{OC}} = 500 \text{ mV}$,
 $J_{\text{SC}} = 18 \text{ mA/cm}^2$,
 $\text{FF} = 45 \%$, $\eta = 4\%$
(AM 1.5, area: 3 mm^2)

M. Nanu, TUD

Interface IV: Interface design in various systems

- (1) TiO_2 / Al_2O_3 / Dye / CuSCN (ECN, UU)
- (2) TiO_2 / $\text{Al}_2\text{O}_3/\text{In}_2\text{S}_3$ / CuInS_2 (TUD, TTU, HMI)
- (3) TiO_2 / $\text{Al}_2\text{O}_3/\text{CdS}$ / CdSe /Electrolyte (WIS)
- (4) TiO_2 / $\text{In}(\text{OH})_x\text{S}_y$ / PbS /PEDOT:PSS Electrolyte (HMI) (ECN)



n-type-layer

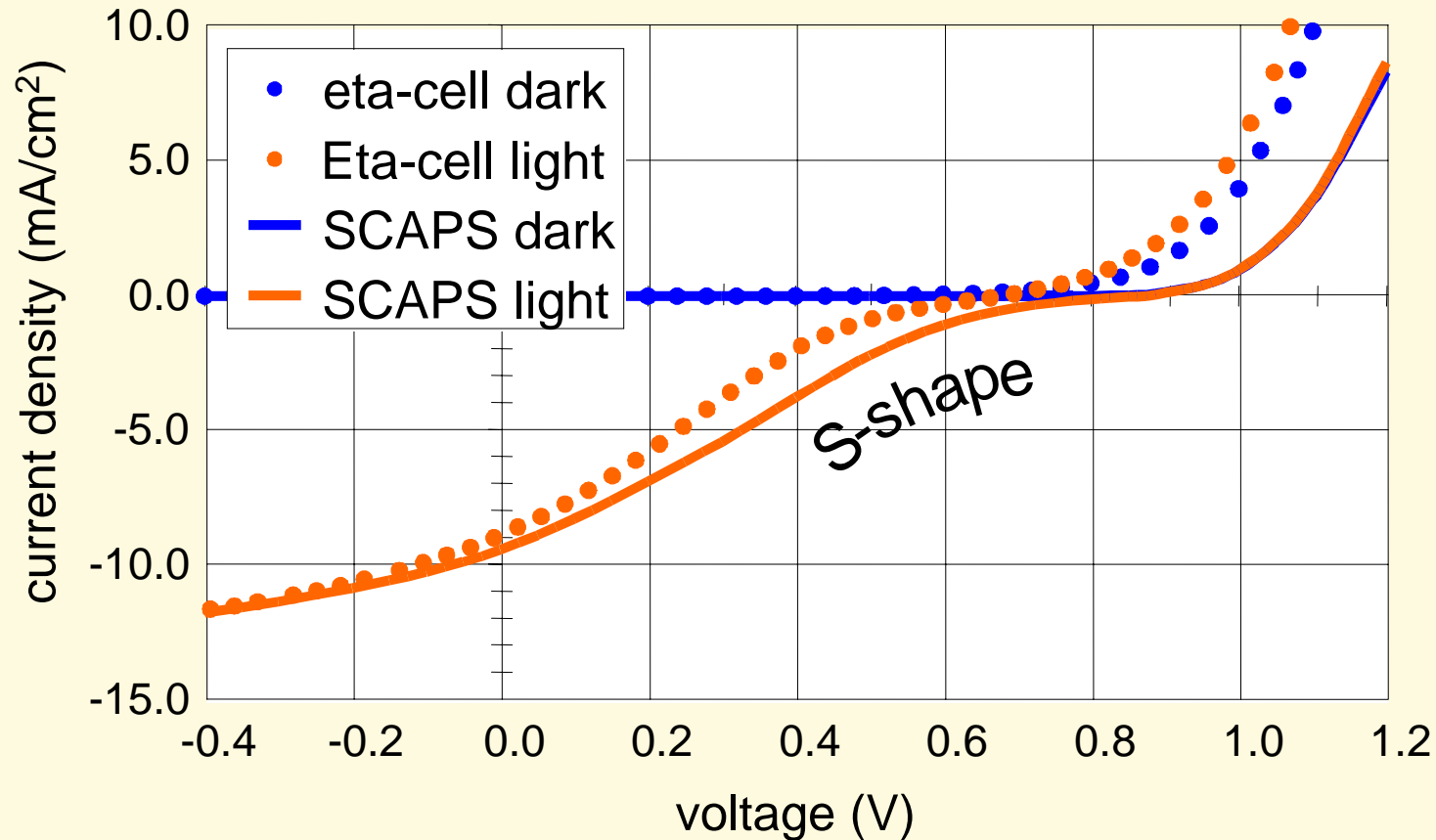


absorber

 = best device setup of the project



Modelling of the first ETA cells (TiO₂/CdTe)

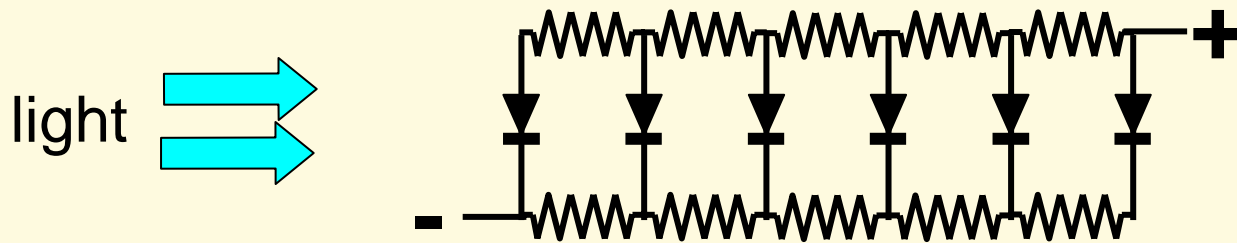


S-shaped I-V curve explained by conduction band offset (0.6 eV)

Modelling the nanostructure

1) Network Model:

A network of small unit cells

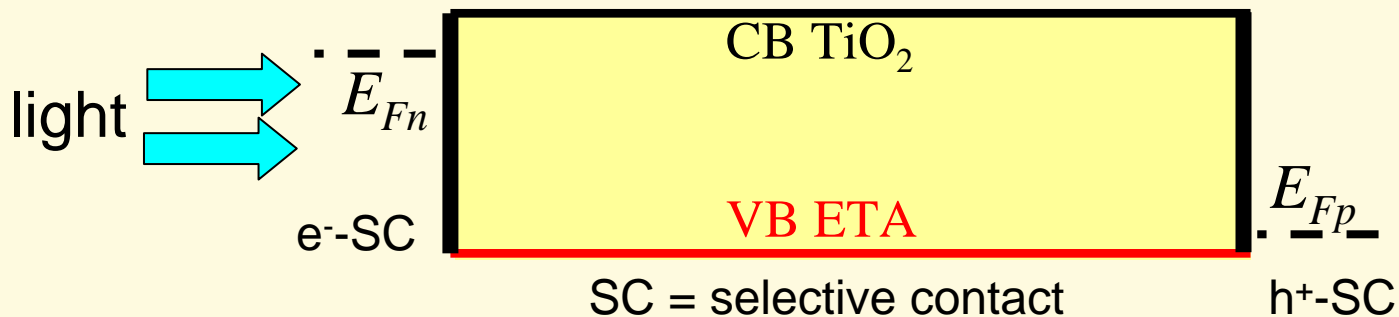


M. Burgelman, C. Grasso J. Appl. Phys., **95**(4) (2004) 2020

M. Burgelman,
C. Grasso - RUG
S. Rühle - WIS
K. Fredin - UU

2) Effective Medium Model

One homogeneous “effective” medium



Overview of the most efficient systems

TiO₂/Al₂O₃/In₂S₃/CuInS₂	4%	(0.03 cm²)	TUD
TiO₂/Al₂O₃/Dye/CuSCN	2-2.5%	(1 cm²)	ECN
TiO₂/CdTe	2%	(< 1 cm²)	HMI
TiO₂/Dye/spiro-OMeTAD	3.5%	(1 cm²)	EPFL
TiO₂/CdSe/CuSCN	2.3%	(?)	CNRS



General Summary

- **Practical realization of working ETA solar cells**
- **Variable group of new systems ($\eta = 2\text{-}4\%$), competitive with other nanocomposite approaches**
- **Interface design of primary relevance**



Future Research Perspectives

- **Deposition techniques (low cost)**
- **Optimizing the microstructure (absorber thickness/interface area)**
 - better performance (?)
 - easier & cheaper preparation
- **Other materials ? (non-toxic, low cost)**



Acknowledgements

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- all our partners for their contributions
- European Commission for funding
(HPRN-CT-2000-00141)

Thank you for your kind attention !

