Photovoltaic Activities in Nordic Countries

Jarmo Skarp

Arrivac

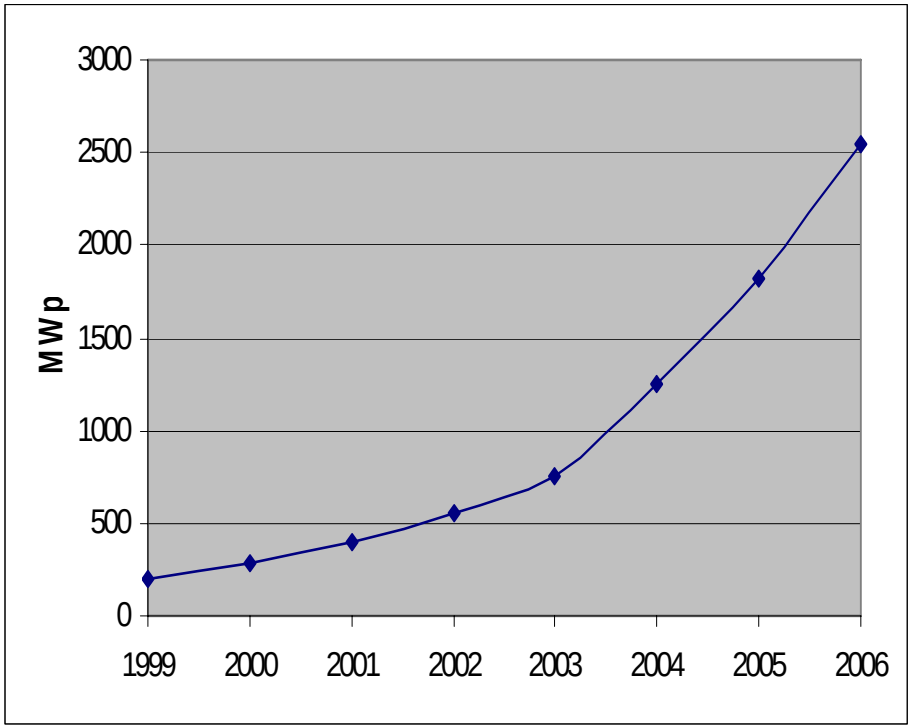
jarmo.skarp@arrivac.com

Outline of the presentation

- Introduction
- PV technologies
  - Silicon wafer type solar cells
  - Thin film solar cells
  - Other
- R&D and PV production in North European Countries
  - Norway
  - Sweden
  - Finland
  - Estonia
- Discussion and summary

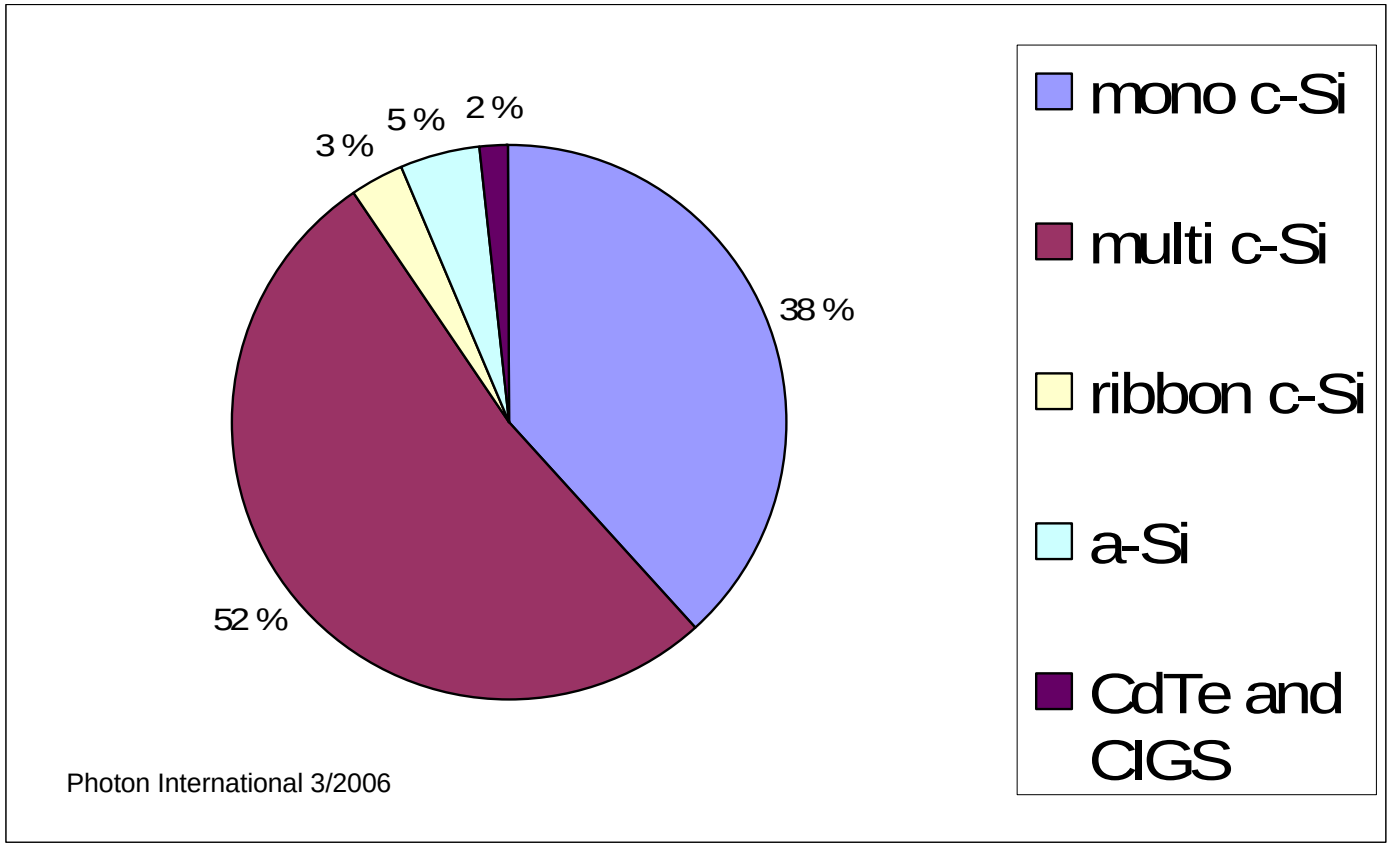
Nordic Countries in This Presentation

The Photovoltaic Market



- 1 MWp is about
  - Area = 10 000 m2
  - Value = 2 - 3 MUSD (factory price)
- Average annual growth rate has been 44%
- Turnover in 2006 was 6 - 7 BUSD
- Feed-in tariff of solar electricity in Germany, Spain, Italy, Greece

Produced PV- Cells in 2005



Silicon wafer type PV cells represent 93.5 % of all produced cells

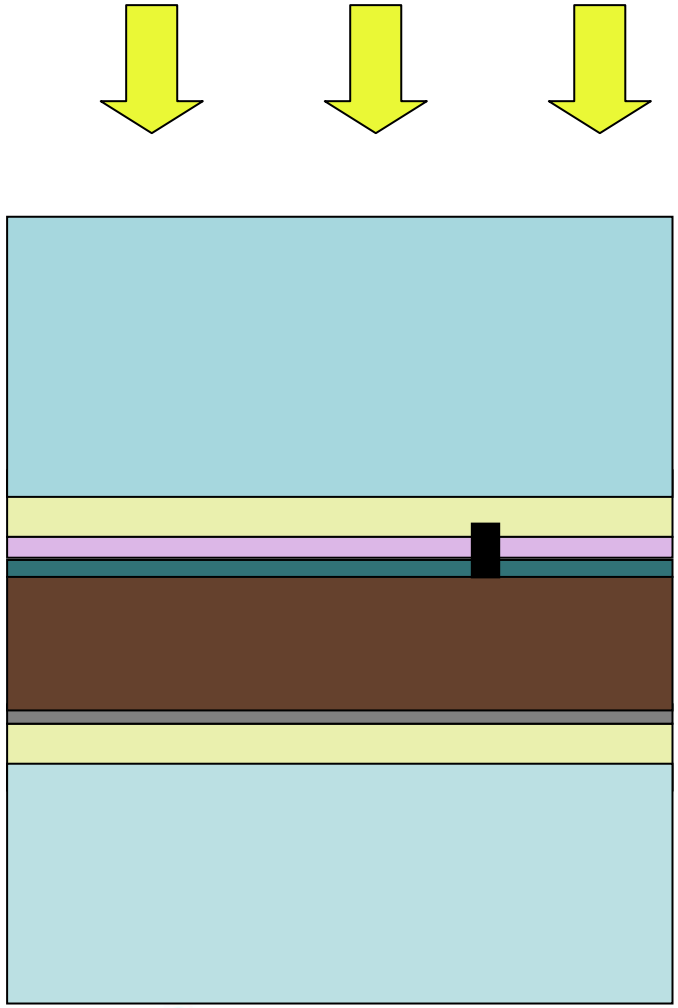
Thin film and silicon cell PV modules

Single crystal Si module

Thin film a-Si module

Schematic Cross Section of Crystalline - Si Cell in Module

(drawing not in scale)



Front glass (tempered, low Fe)

EVA or other adhesive

Front electrode,
Ag thick film

AR-coating SiN:H

n-type silicon (emitter)

p-type silicon (base)
(absorption layer)

Al back electrode (thick film)

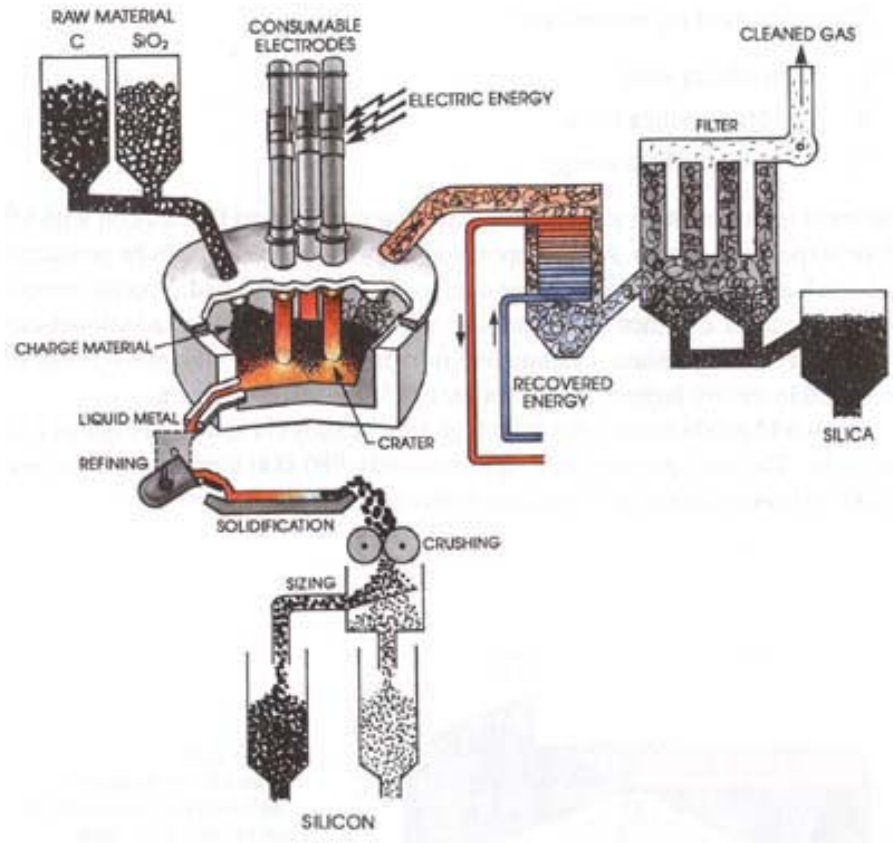
EVA or other adhesive

Rear cover
(glass or Tedlar)

Manufacturing flow in six steps

50 % of Module cost	1.	Silicon production: SiO2 -> metallurgical silicon (m-Si)
	2.	Purification: m-Si -> poly Si
	3.	Crystal growth: poly Si -> single/mono Si ingot or multi crystal block
	4.	Wafer slicing
25 %	5.	Cell manufacturing
25 %	6.	Module assembly

1. Silicon production: SiO2 -> metallurgical grade silicon (mg-Si)



From: NTNU

- $SiO_2 + C \rightarrow Si + CO_2$
- Done at 1900 C
- Silicon purity 98 %
- Metallurgical silicon is mainly used in Al and other metal alloys
- World annual production about 1 M tn (230 k tn in Norway)

Back

2. Purification: mg-Si -> poly Si

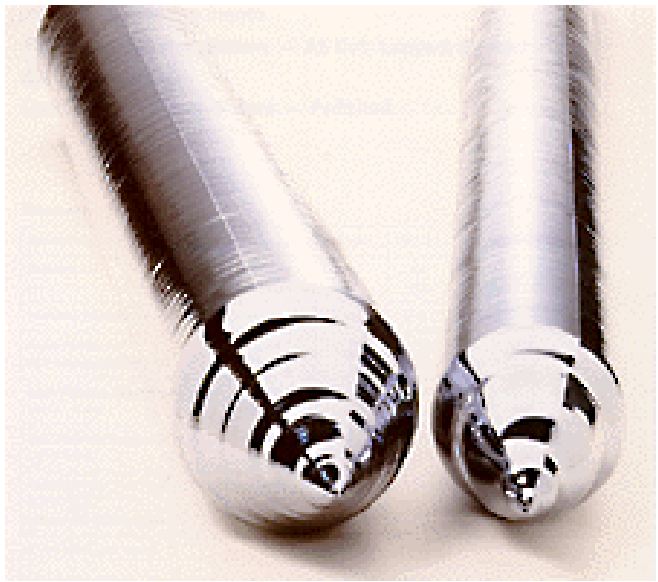
Polysilicon chips from Wacker

- Si (s) -> SiCl4 (liq) or HSiCl3 (liq) or SiH4 (liq)
- Purification of the liquid in distillation process
- Convert compound back to polysilicon
- Impurity level about 1 ppm
- Producers: Hemlock (USA), REC (USA), Wacker (GER), Tokuyama (JPN), MEMC (USA), Mitsubishi (JPN) and Sumitomo (JPN)
- Annual production in 2005 was about 50 000 tn

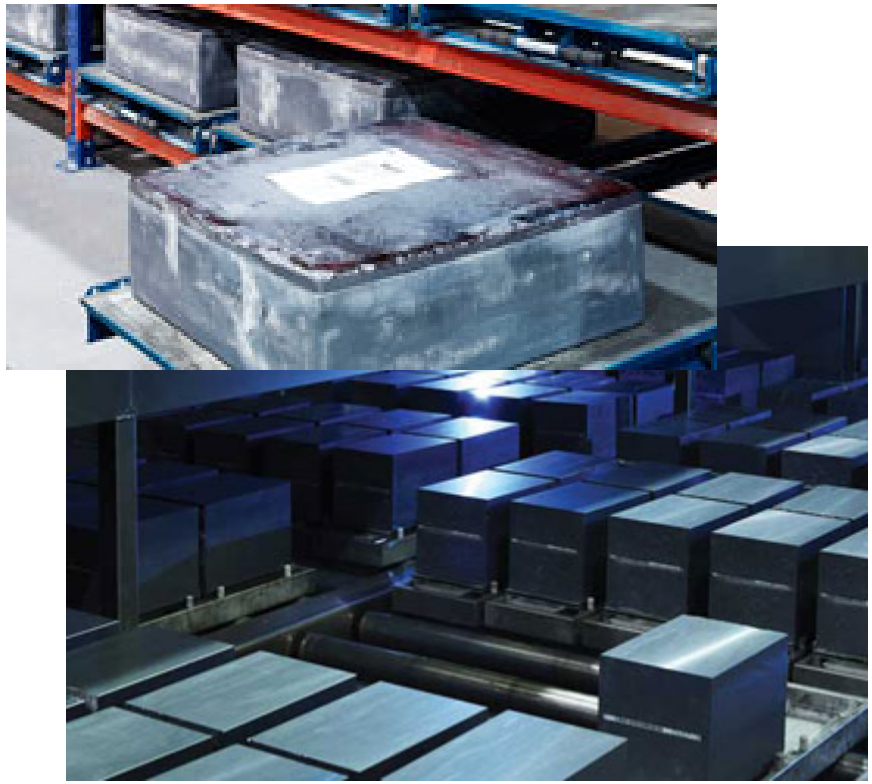
Back

3. Crystal growth

- Single crystal ingot

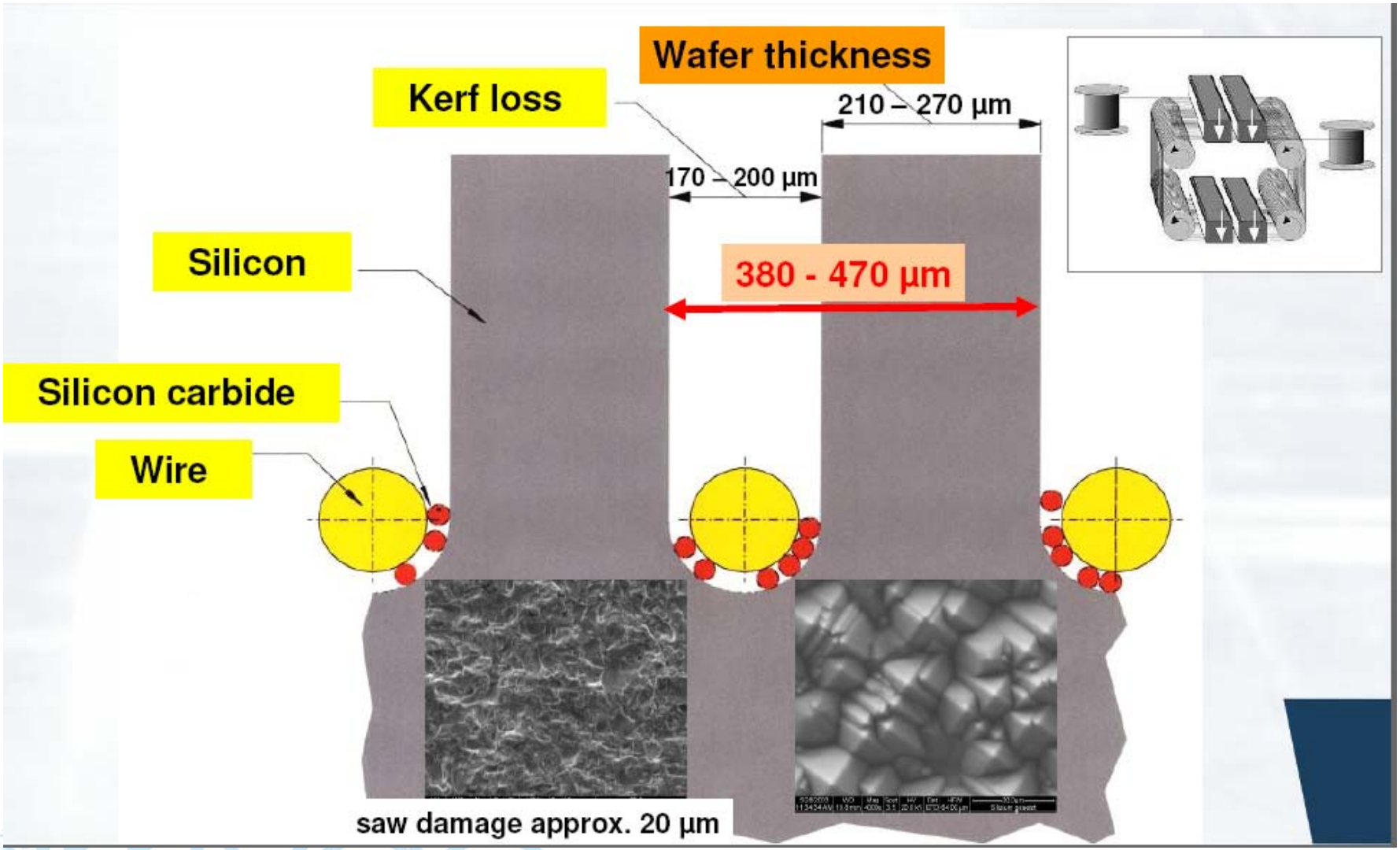


- Multicrystalline block and bricks



Back

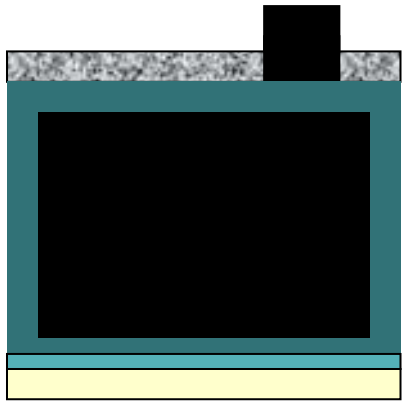
4. Wafer slicing

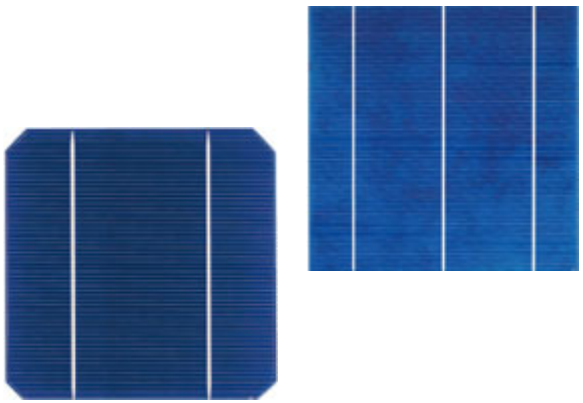


Dipl. – Ing. Boris Klebensberger
COO SolarWorld AG

Back

5.a Manufacturing of Standard (15%) Cell (p-type mono- or multicrystalline wafer)

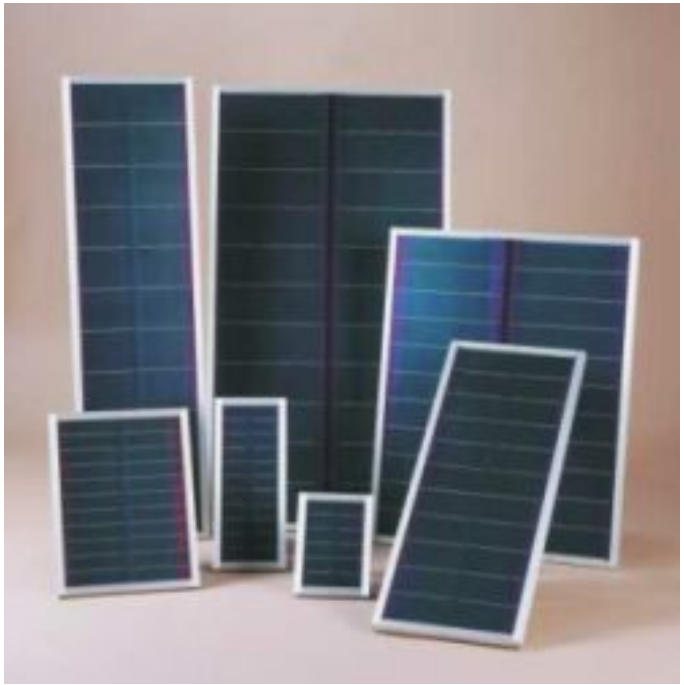




1. Saw damage etching (10 um off from both sides of wafer). Texturing of the front surface in the case of sc-Si.
2. n-type doping of the front surface of the p-type wafer. Phosphorous containing material (POCl3, P2O5, PSG, etc) at high temperature (800 -1000 C).
3. PSG etching. Back side etching. Edge isolation
4. Front surface passivation and ARC: PECVD SiNx
5. Front contact formation: narrow grid of Ag-paste by screen printing on SiN. Firing through the ARC.
6. Rear contact: screen printed Al. p^+ - layer is formed by Al doping at temperatures higher than 600 C.

Back

6. Module assembly

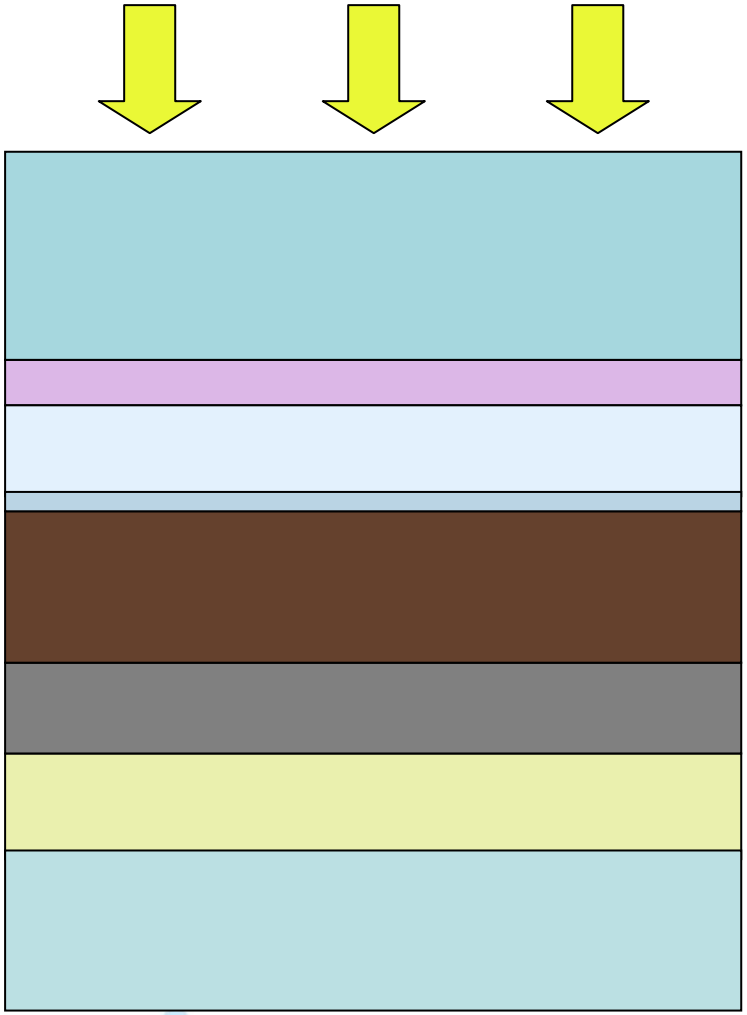


- Solder lead stripes in cells (tabbing).
- Connect cells in series (strings)
- Connect strings in series
- Laminate strings between front and rear plates with two EVA films
- Connect junction box
- Assemble frame (if used)

Back

Generic Thin Film PV-cell

(drawing not in scale)



Transparent substrate (Glass)

AR-coating (optional)

Transparent conductor (TCO)

n-type semiconductor (window layer)

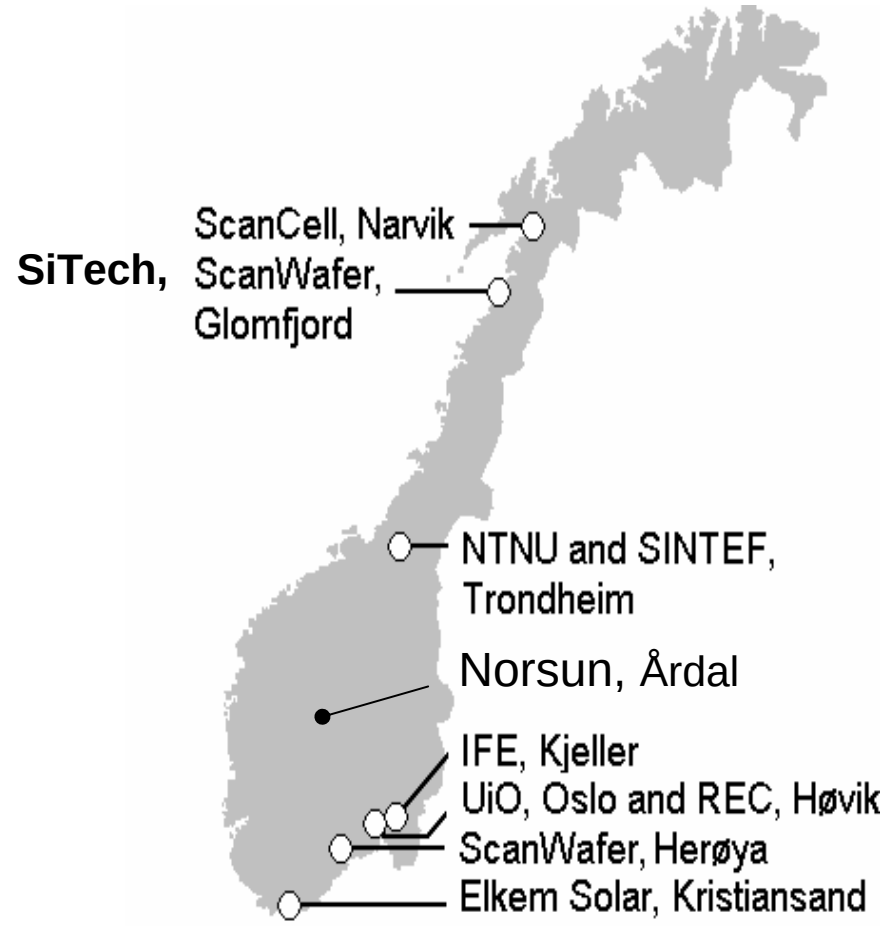
p-type semiconductor
(absorption layer)

Back electrode (metal or TCO)

EVA or other adhesive

Rear cover
(metal or Tedlar or glass)

Norway:
Crystalline Silicon PV Industry



- Companies
  - REC
    - REC Silicon (USA)
    - ScanWafer
    - SiTech AS
    - ScanCell
    - ScanModule (Sweden)
  - Elkem
  - Norsun

  Size (in 2006)
  - 1100 employees
  - 420 M€

Norway:
PV Products and the Year of Start

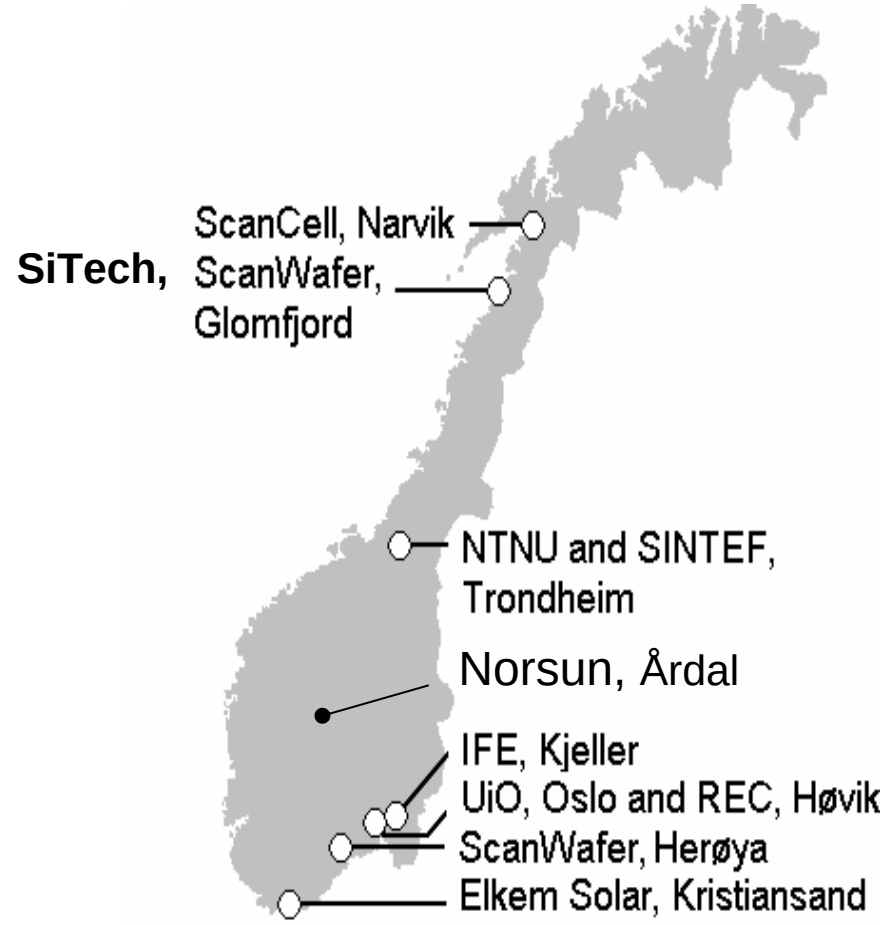
	REC/2000	Elkem/1904	Norsun/2006
mg-silicon		In 1910's	
Poly-silicon	USA/2002	2008	Saudi-Arabia
Ingots/blocks	1997		2008 (2007 Okmetic/Finlad)
Wafers	1997		Singapore
Cells	2003		
Modules	Sweden/2003		

Green = plan

REC

Producers	Process & technology	Total Production (tons or MW)	Maximum production capacity (t/yr or MW/yr)	Product destination?	Price
REC Silicon (in the USA)	Silicon feedstock	5 600 tons	6000 tons	Production in the USA for global market	na
REC SiTech	sc-Si ingots mc-Si ingots sc-Si wafers	31 MWp	40 MWp	Asia	na
REC ScanWafer	mc-Si wafers	275 MWp	360 MWp at end of year	53 % sale to Asia (mostly Japan). 47% sale to Europe (mostly Germany)	na

Norway:
Research on Crystalline Silicon PV



- Universities and Research Institutes
  - Norwegian University of Science and Technology (NTNU)
  - SINTEF
  - Institute for Energy Technology (IFE)
  - University of Oslo (UiO)

Sweden: Thin Film R&D and Si-module manufacturing

- CIGS Thin film
  - Uppsala University
  - SOLIBRO Reseach AB (Q-Cell/GER)
  - Midsummer AB
- Si-module manufacturing
  - Artic Solar (SolarWorld/GER)
  - GSV (Alfasolar/GER and NAPS Systems/FI)
  - *n67 Solar AB*
  - ScanModule (REC/Norway)
  - PV Enterprise
- Dye Senzitized Solar Cells
  - Center of Molecular Devices at KTH
- Size (in 2006)
  - 400 employees
  - 240 M€

Produced modules and production capacity of PV modules in Sweden

Cell/Module manufacturer	Technology (sc-Si, mc-Si, a-Si, CdTe)	Total Production (MW)			Maximum production capacity (MW/yr)		
		Cell	Module	Concentrators	Cell	Module	Concentrators
1 GPV	mc-Si	-	17	-	-	50	-
2 ArcticSolar	mc-Si	-	3,1	-	-	20	-
3 ScanModule	mc-Si	-	33	-	-	45	-
4 PV Enterprise	mc-Si	-	2,3	-	-	20	-
5 n67 Solar	mc-Si	-	-	-	-	-	-
TOTALS		-	55,4	-	-	135	-

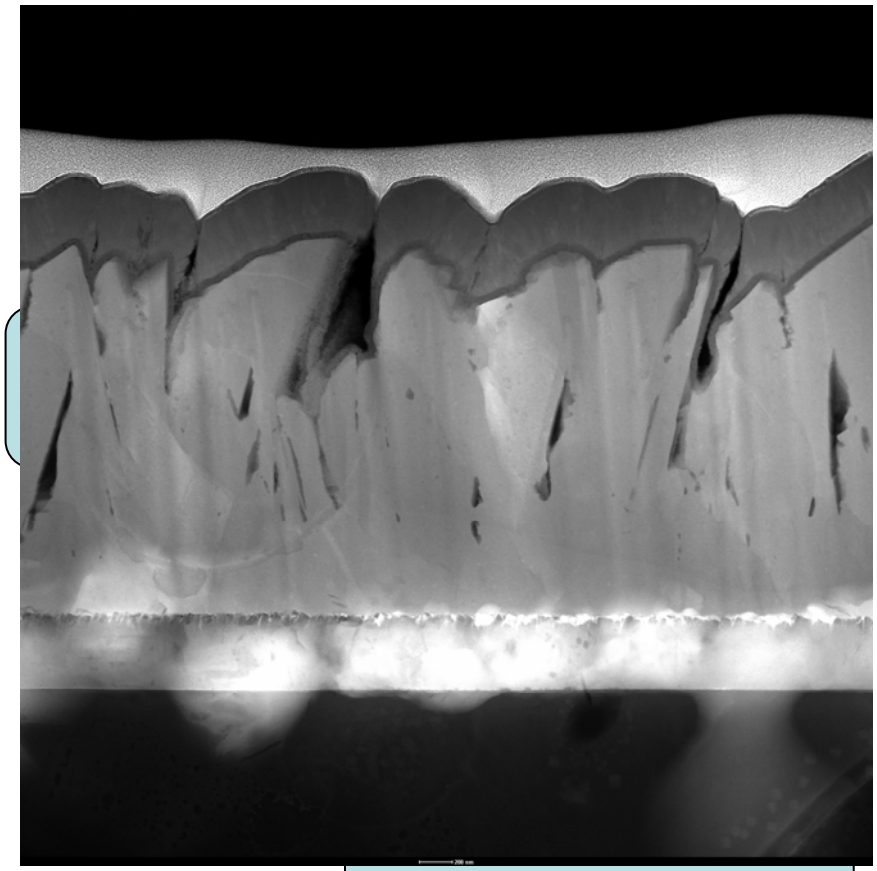
IEA Report: PV Production in Sweden in 2006

Uppsala CIGS case

Price: 8 M€

- Research on CIGS started in early 1980 in Stockholm
- Group moved to Uppsala (Ångström Solar Center) in 1994
- Several world records of efficiency of CIGS cells, the best 18.5 %
- Spin-off company Solibro founded in 2002
- German company Q-Cell buys the majority of Solibro
- Manufacturing plant in Germany

Price: 60 – 70 M€



Uppsala

Estonia: Tallinn Technical University

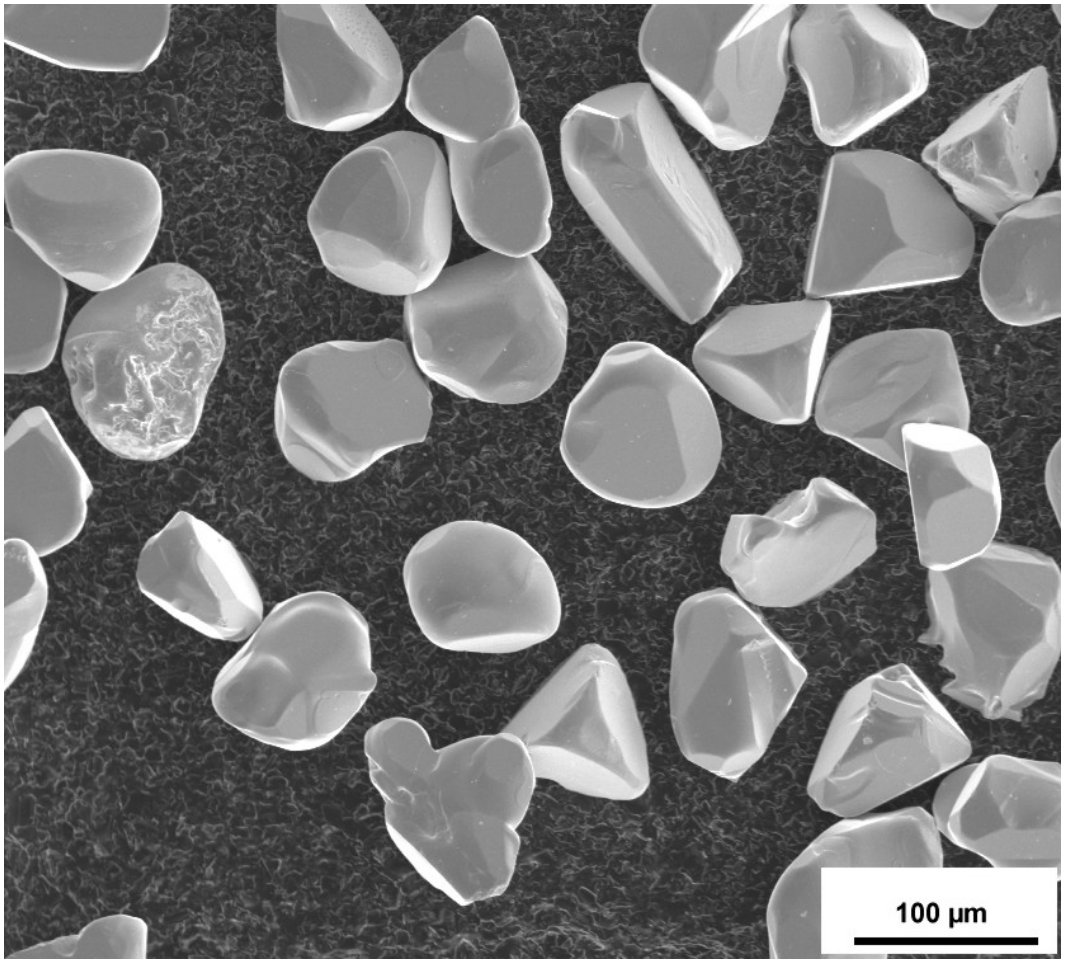
History

- 1960 II-VI materials research group at TTU
- 1987 Laboratory of Optoelectronic Materials
- 1991 - Partner in several EU PV Research Projects
- 2002 EU Centre of Excellence in PV Materials and Devices
- 2007 Nordic PV Centre of Excellence

Team

- Research staff: 36
- Junior researchers: 19
- Post-docs: 2
- PhD students: 14
- PhD in 2003-2007: 10

Monograin powder of $CuInSe_2$



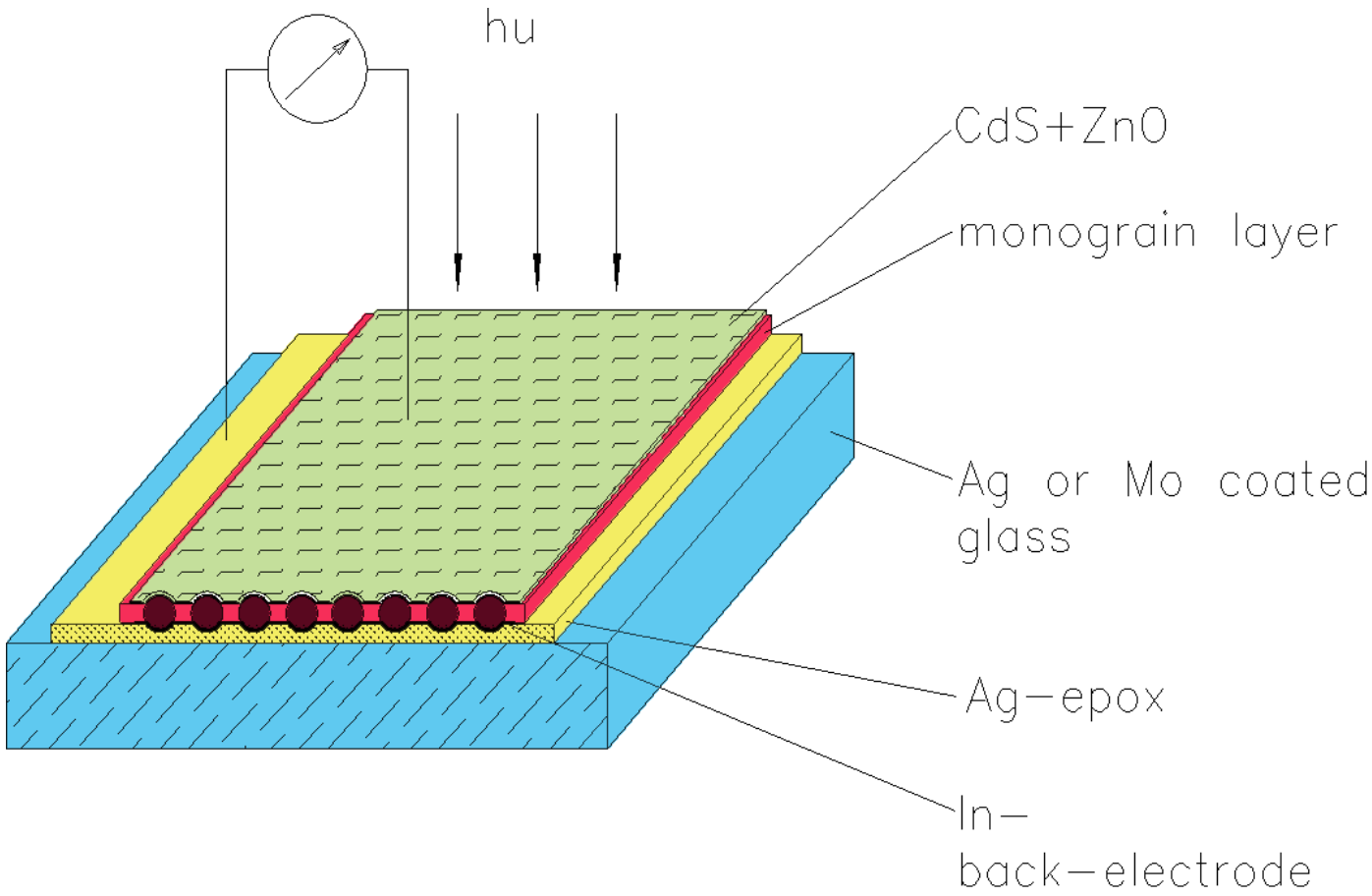
The advantages of the developed powder materials are:

1. single-crystalline structure of every grain;

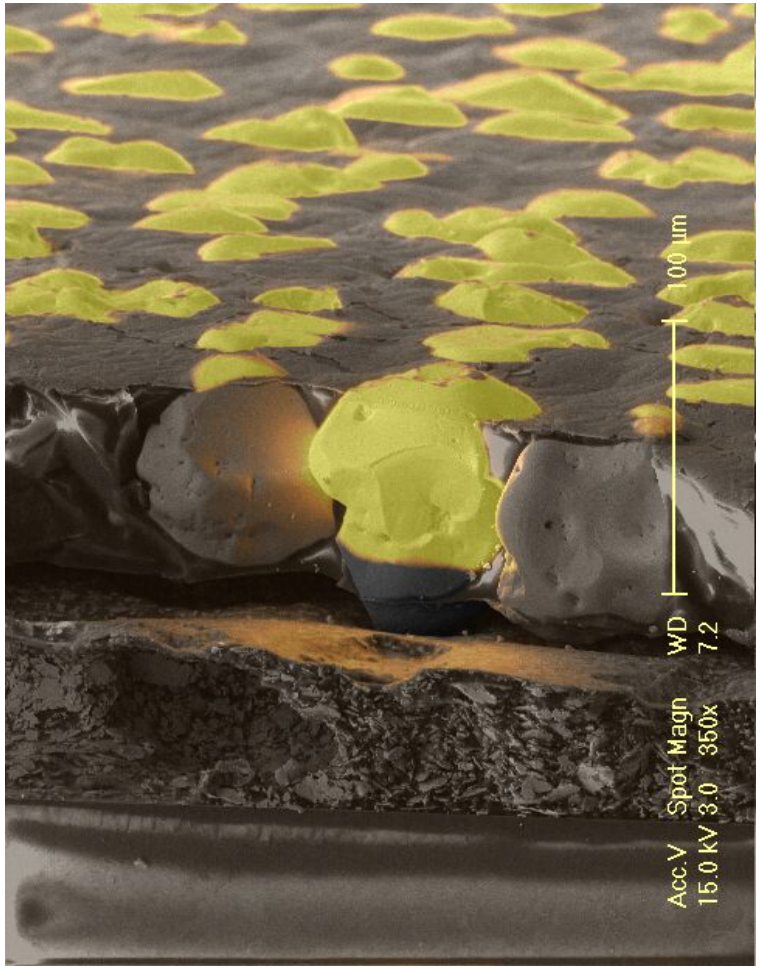
2. narrow granulometric composition;

3. uniform molecularity, stoichiometry and distribution of doping impurities in material

Monograin layer



EBIC picture monograin layer solar cell



Tallinn Technical University

Finland: Fragmented PV Industry

- NAPS Systems: PV-systems provider
  (Microchemistry 1987 – 1997)
- Endeas: Solar simulators
- LUVATA: Copper ribbons
- Okmetic: Technology know-how on single crystal silicon manufacturing
- Braggone: Materials for new type of ARC
- Beneq: Large area ALD equipment
- Arrivac: Consulting
- Research:
  - Dye Sensitized Solar Cells in TKK (Helsinki)
  - Organic Solar Cells in TTKK (Tampere)

Nordic Co-Operation on PV

- Nordic Centre of Excellence in Photovoltaics
  - Institute for Energy Technology (IFE)
  - Danish Technological Institute
  - Helsinki University of Technology
  - Norwegian University of Science and Technology
  - Uppsala University
  - Ioffe Physico-Technical Institute in St. Petersburg
  - Tallin University of Technology.
- **Scandinavian Photovoltaic Industry Association**, SPIA, based in Stockholm (www.solcell.nu).

Summary

- Norway has become a world class player in crystalline silicon PV production
- Industry related research topics in different countries: c-Si in Norway, CIGS in Sweden, mono-crystalline grains in Estonia
- Multinational co-operation in Nordic countries, within EU and global scale (manufacturing)
- Sunny prospects!

Acknowledgements

I would like to thank following persons for their inputs to this presentation :

- Dr. Fritjof Salvesen / Norway
- Dr. Ulf Malm and Dr. Lars Stolt/ Sweden
- Prof. Enn Mellikov/ Estonia