Applied Solar Energy

A.Goetzberger

Fraunhofer Institute for
Solar Energy Systems ISE

Fraunhofer Institut
Solare Energiesysteme

Fraunhofer Institut
Solare Energiesysteme

Contents

- Photovoltaic materials: Past and Future
- Modeling future efficiencies
- PV and Agriculture
- Solar thermal systems and solar buildings
- The self sufficient solar house
- PV in a future decentralized energy system

Fraunhofer Institut
Solare Energiesysteme

Photovoltaic Materials

- **Past: In the beginning there was silicon**
- **Present: It‘s still silicon**
- **Future: Silicon or ???**

Fraunhofer Institut Solare Energiesysteme

Past

- 1954 First solar cell (Chapin et al.), efficiency 6%
- First applications in space vehicles
- Technology: Chochralski grown crystals, sawed wafers, pn junctions by diffusion

Fraunhofer Institut Solare Energiesysteme

Present

- **Dominance of market by crystalline silicon, with multicrystal growing faster than monocrystal**
- **Supply of silicon is critical. Reliance on reject silicon from semiconductor market leads to shortages. Solar silicon is required**
- **Cell efficiency stands at 24.7% in laboratory and 12 - 16% in production**
- **Efficiency is of great importance because of area related cost**

Fraunhofer ISE Institut Solare Energiesysteme

Mid Term Future: Three potential scenarios

- **Continued dominance by evolution of the present Si single crystal or cast polycrystal technology**
- **New crystalline Si film materials of medium thickness (5-50µ) either as ribbons or on foreign substrates**
- **Breakthrough of true thin film materials like a-Si or CIS or CdTe**

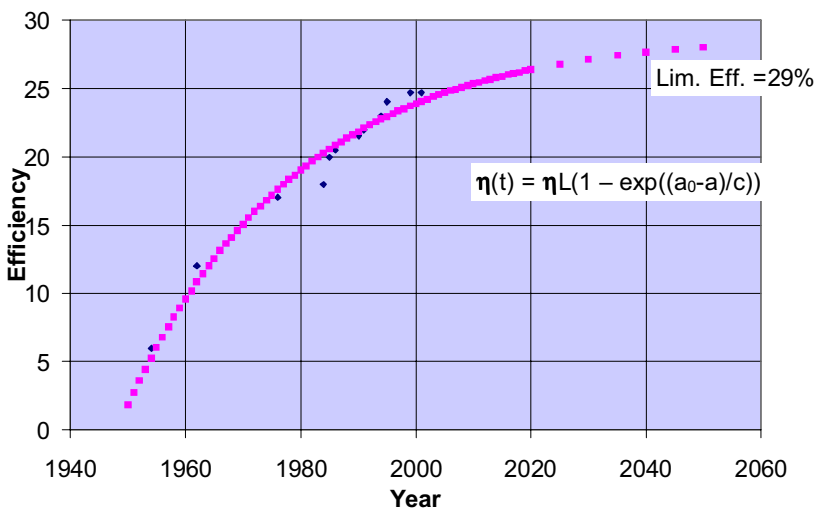
Fraunhofer ISE Institut Solare Energiesysteme

Modeling the past and future development of solar cell efficiency

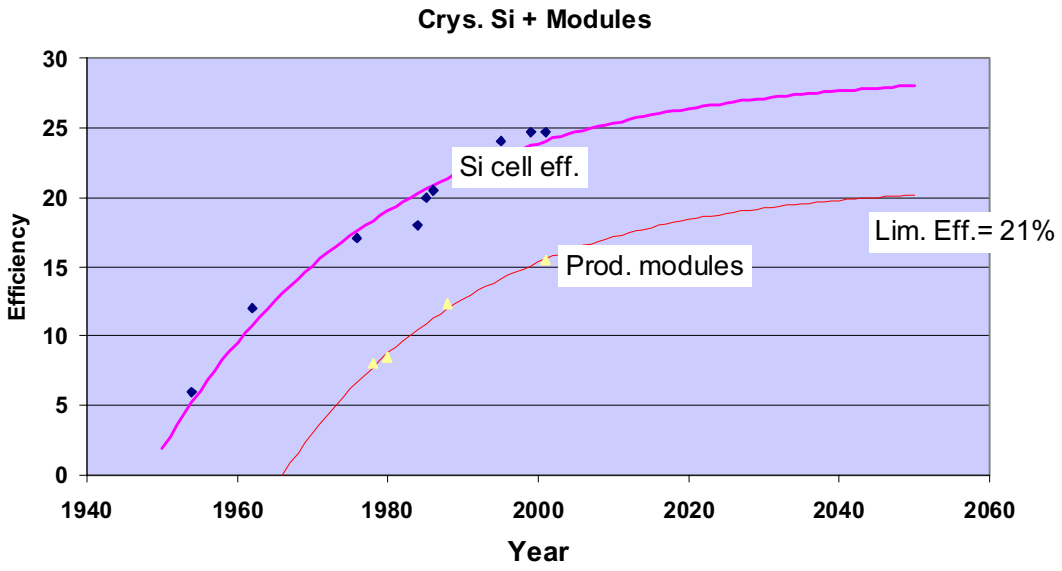
- **Properties of the modeling function:**
  - **It starts at a given point in time**
  - **After long development it reaches an asymptotic value**
- **The function for efficiency η is:**
  - $\eta(t) = \eta_L(1 - \exp((a_0 - a)/c))$

With η_L = final efficiency, a_0 = start of development (year), c = constant. η_L , a_0 ,c are empirical constants determined from data

Fraunhofer Institut Solare Energiesysteme



Fraunhofer Institut Solare Energiesysteme

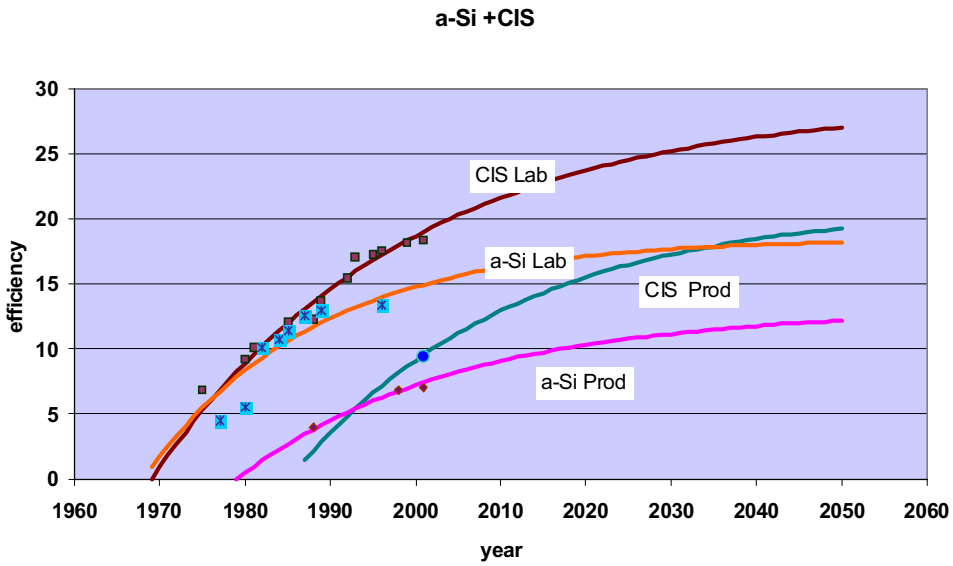


Fraunhofer Institut Solare Energiesysteme

Ongoing development of crystalline silicon

- **Crystalline ribbon and film technologies (commercial)**
  - **EFG Ribbons (by ASE)**
  - **Silicon Film (by Astropower)**
  - **Evergreen Technology**
- **A-Si/C-Si Heterostructures: Very promising development (Sanyo)**
- **Thin crystalline films (5-50µ) on foreign substrates**
  - **Deposition by liquid phase epitaxy (LPE) low temp.**
  - **Deposition by chemical vapor deposition (CVD) high temp**
  - **Transfer techniques**

Fraunhofer Institut Solare Energiesysteme

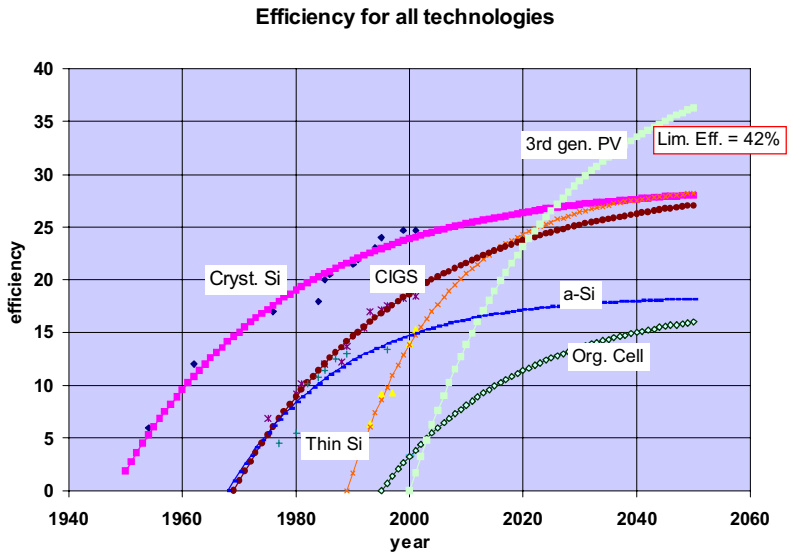


Fraunhofer Institut Solare Energiesysteme

Long Term Prospects

- **Dye sensitized cells**
- **Concentrating systems**
- **Tandem cells**
  - **Stacked thin film solar cells with different bandgaps**
- **Polymer (organic cells)**
  - **Low efficiency but potentially very cheap**
- **Third generation materials and technologies**
  - **Intermediate band material, Multiple carrier generation material, Hot carrier cells, Thermophotovoltaic devices, Micro antenna cells, etc.**

Fraunhofer Institut Solare Energiesysteme



Fraunhofer Institut Solare Energiesysteme

Applications of thermal solar energy

- Domestic hot water heating
- Space heating
  - Combi-systems (water + space heating)
  - Seasonal storage in large scale storage units
- Air conditioning
  - High efficiency collectors are available
  - Adsorption system operate at temperatures ~100°C

Fraunhofer Institut Solare Energiesysteme

Collector Technology

Original Technology	Present Trends
Cheap, unreliable, low efficiency	High quality, high efficiency, proven lifetime
Production: Wet chemistry, environ-mentally hazardous	Now: Vacuum technologies
Standard product cover glass	Low iron glass with anti-reflective surfaces

Fraunhofer Institut Solare Energiesysteme

Solar Architecture

- Originally: Passive solar energy, components and design for thermal comfort only
- Today: Integrative systems approach, heating, cooling, ventilation, daylighting, PV integration

Fraunhofer Institut Solare Energiesysteme

The Self Sufficient Solar House

Fraunhofer Institut Solare Energiesysteme

Summary 1: PV

- Presently cryst. silicon is the dominant solar cell material
- Modelling of past efficiencies: → prediction for the future
- Many options exist for future improvement of efficiency and cost

Fraunhofer Institut Solare Energiesysteme

Summary 2

- Collector technology is mature
- Passive Solar has developed into Solar Architecture
- PV and agriculture are compatible
- PV fits well into a future decentralized energy system

Fraunhofer Institut Solare Energiesysteme