



Nanotech for CO₂-free energy generation

- *Nano for efficiency* -

Werner Hoheisel

Bayer Technology Services GmbH

Bayer Working Group Nanotechnology

Working Group Nanotechnology

Fona, Berlin
2008-09-24

Bayer's contribution to reach the challenging „climate targets”: Reduction of greenhouse gases

... the pressure of the regulatory offices increases

Kyoto-protocol: Reduction of greenhouse gases by 5,2 % by 2012

G8-Countries: Reduction of greenhouse gases by 50 % by 2050

EU Reduction of greenhouse gases by 20 to 30% by 2020 and the emissions by cars to 120 g CO₂/km

National measures of non-signing countries:
e.g. California will reduce greenhouse gas emissions by 25 % until 2020

Bali Roadmap for the time after Kyoto: agreement expected by end of 2009



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Climate Change: Trends on the market

Does this necessarily mean a major problem for industry interests?
→ Climate protection and economic thinking is ***no contradiction!***

→ more cost-effective production, new products

Efficiency of production units and infrastructure

Insulation of buildings, refrigerators and cooling vehicles

Weight reduction and improved aerodynamics in the transportation section

Highly efficient LEDs for lighting

New materials and high-tech compound materials for renewable energy supply

Renewable raw materials



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Nanotech to reduce CO₂-emission

- How can Nanotech contribute to climate friendly products?
- Properties of nanostructures and their relation to sustainable energy management:
 - Small volume, nanostructures, small pores, large specific surface
 - Lightweight and stable nanocomposites
 - Thermal insulation
 - OPV
 - Adjustable physical properties (e.g. QSE)
 - OPV, QLED
 - Preparation as inks and handling of dispersions: Printable, castable
 - Low cost and little energy consuming processing



Many well known "nano-properties" which may be employed for devices, components that contribute to sustainable energy management → nanotech as part of value chain

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Bayer's activities in energy related nanotech

Examples:

- **Passive systems**
 - Thermal insulation
 - Lightweight nanocomposites
 - ...
- **Active systems**
 - (Organic) Photovoltaic
 - Conductive microstructures
 - Fuel cells
 - Li-ion batteries
 - ...

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Well-known: Polyurethane for thermal insulation



BaySystems® (Baydur®, Baytherm®, Desmodur®)

- Excellent insulation properties for energy savings
- Climate and ozone friendly foaming agent

1 kg Polyurethan saves
79 kg CO₂e-emissions (in 10 a)

Baymer®, Desmodur®

- Excellent insulation properties
- Less air leakages in buildings

1 kg Polyurethan saves
360 to 755 kg CO₂e-emissions (in 50 a)

Energy savings: > 100x of energy for total
product life cycle

Polyurethane for thermal insulation



Nanotechnology has potential to increase the efficiency even more

- ➔ Pore size < mean free path of gas molecules
- ➔ Less heat transfer by reduced heat convection

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Carbon Nanotubes for high strength nanocomposites

Generation of Electricity by Wind Power



7 t blade



Nanocomposites allow to produce more stable blades for light weight wind mills

Higher efficiency → competitive renewable energy sources

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baytubes® dispersions and composites (passive)

0,05 w.-% CNT

Agglomerates of CNT (98% purity)

Powder

Techniques

- in-situ polymerisation
- Melt impregnation
- Solvent impregnation

Complete dispersion in PC if CNT produced with specific catalyst and well defined processing parameters (T, t, hydrocarbons,...)

PC

Polyol

PA

$\varnothing = 5 - 20 \text{ nm}$
 $L \gg 1 \mu\text{m}$

Additionally, if necessary for special applications

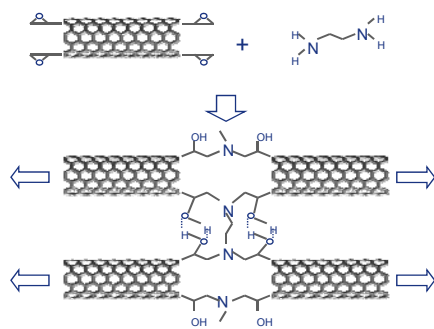
- High degree purification
- Disentangling
- Surface modification
- Chemical functionalization

Handle macro, get nano!

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baytubes® dispersions and composites (active)

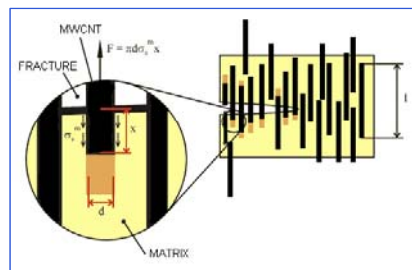
Functionalization of MWCNT (Baytubes®) in cooperation with Amroy Oy HYBTONITE®



Hybride-MWCNT's as local reinforcement

- Hybrid nanotubes with covalent bonds between CNT's and resin molecules.
- Covalent matrix structure resin curing.

Fracture:



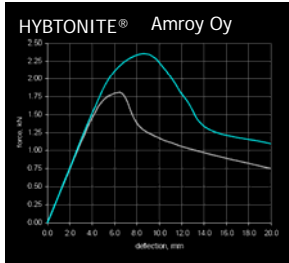
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baytubes® composites: reinforcement

Properties of baytubes® epoxy nanocomposite (0,5%)



3p-bending tests of two similar carbon fibre laminates. Hybtonite® epoxy matrix (upper curve), SP Prime20 epoxy matrix (lower).

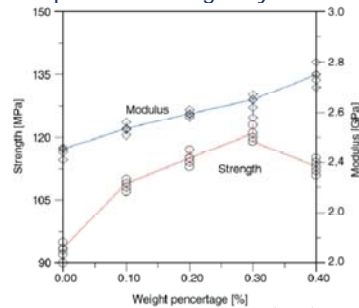


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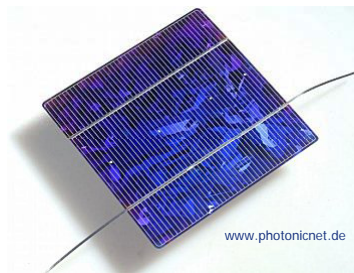
HYBTONITE technology with improved properties:

- Impact strength by 20-30 %
- Fatigue by 50-200 %
- Lower the weight by 10-30 %
- Compression strength by 10-20 %

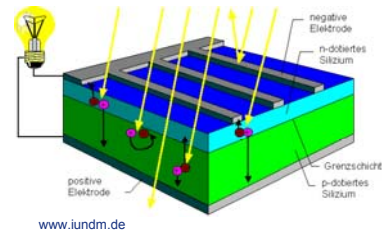


Zhou et al. - EXPRESS Polymer Letters 2(2008)40-48
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1st Gen Solar cells: c-silicon



www.photonict.net



www.iundm.de

Classical c- or mc-silicon cells need **thick, high-quality Si-wafers** (> 100 µm) for effective sunlight absorption and long exciton diffusion lengths to interface

➡ Established and nanotechnology is not involved, ...

... except the **fingergird electrodes**

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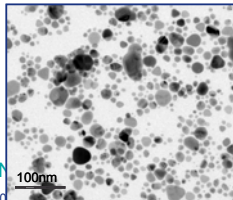
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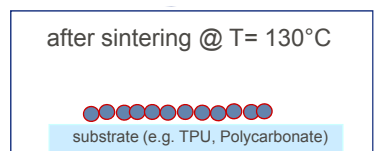
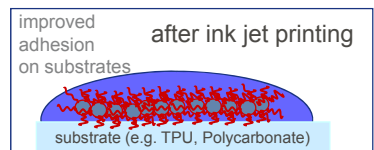
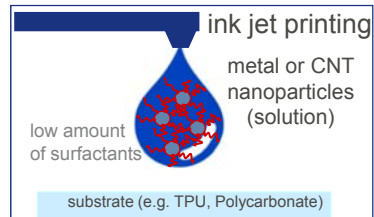
Conductive Microstructures

Approach

- Production of a dispersion of suitable particles
 - Synthesis of nano silver (\rightarrow BayInk[®])
 - Dispersion of MWCNT (\rightarrow Baytubes[®])
- Printing on flexible substrates
 - Inkjet printing (down to 30 μm)
 - Screen-printing
- Sintering process
 - Low sintering temperature ($< 130\text{ }^\circ\text{C}$)
 - 155 $\text{m}\Omega/\square$ (2 μm thick)
 - **$6 \cdot 10^6\text{ S/m}$ (10 % of bulk silver)**

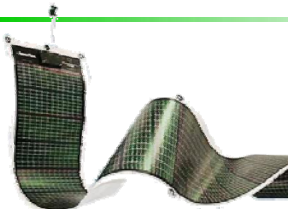


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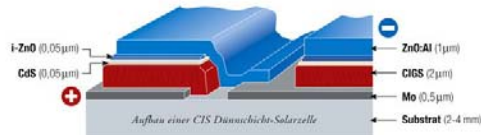


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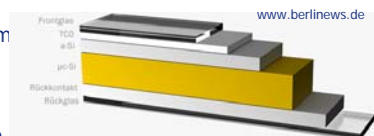
2nd Gen Solar Cells: Thin Film PV (CIGS, a-, μ -Si,...)



www.gotsolar.com



- Due to high absorption yield much thinner cells ($< 5\text{ }\mu\text{m}$) are feasible even on flexible substrates.
- Heterojunction: Low density of structural defect states necessary for long exciton diffusion lengths to interface
- Processing mostly by evaporation processes
 - \rightarrow New approach e.g. by Nanosolar
 - \rightarrow nanoparticle ink (printing + annealing)



www.nanosolar.com

Nanotechnology for cheaper processing

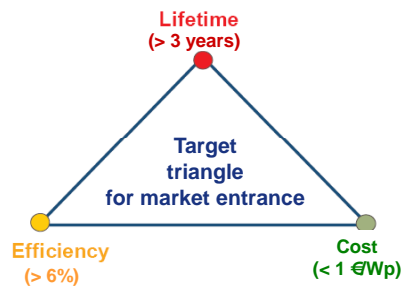
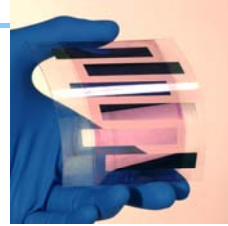
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3rd Gen solar cells: OPV

- Inexpensive energy source
- Flexibel substrates
- Roll-to-roll processing
- Entrance market: "mobile" applications (off-grid)
- Minimum targets:



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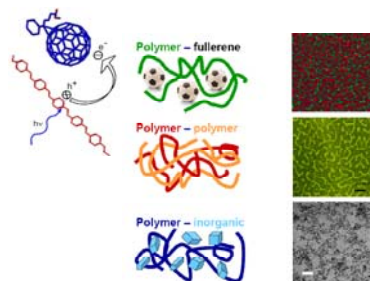
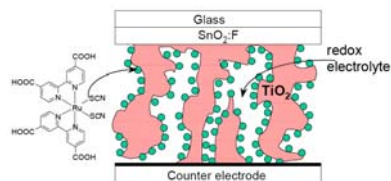
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3rd Gen solar cells: OPV

3 Types (all strongly driven by nanotech)

- **Dye sensitized solar cells (DSSC)**
- OPV based on **small molecules**
- OPV based on **sc-polymers**
 - Fullerene-derivates and p-type polymers (e.g. polythiophenes, polyphenylvinylen,...)
 - Pure n- and p-type polymers
 - Nanoparticles and p-type polymers (e.g. quantum dots, ZnO, TiO₂,...)



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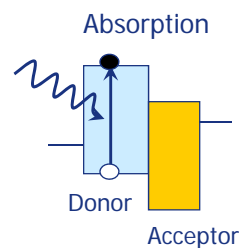
Bayer Technology Services Janssen et al.

OPV and nanotech

- **Common feature for OPV: Low exciton diffusion length < 10 nm**
- **Consequence: Nanotechnology is essential for OPV**
 - Control of structure and morphology on the nanoscale
 - Large scale multilayer system with thicknesses of ~ 100 nm

- **Requirements for material and morphology**

- **Material:** High absorption ($> 10^5 \text{ cm}^{-1}$)
 - Polymers and direct semiconductors are effective absorbers with absorption lengths of ~ 100 nm



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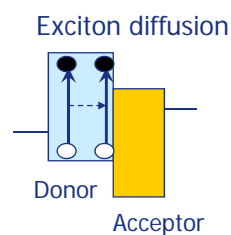
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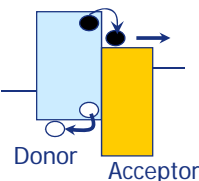
OPV and nanotech

- **Requirements for material and morphology**

- **Morphology:** Small distance to interface
 - Low exciton diffusion length ($< 10 \text{ nm}$)
 - Nanostructuring is essential for exciton to find an interface
 - Most losses due to recombination
- **Material combination:** Ultrafast charge separation/dissociation at interface ($< 100 \text{ fs}$)
- **Morphology & Material Charge carriers:** Charge collection – Fast track with low resistance to electrodes
 - high carrier mobility with few contact points



Charge separation & collection



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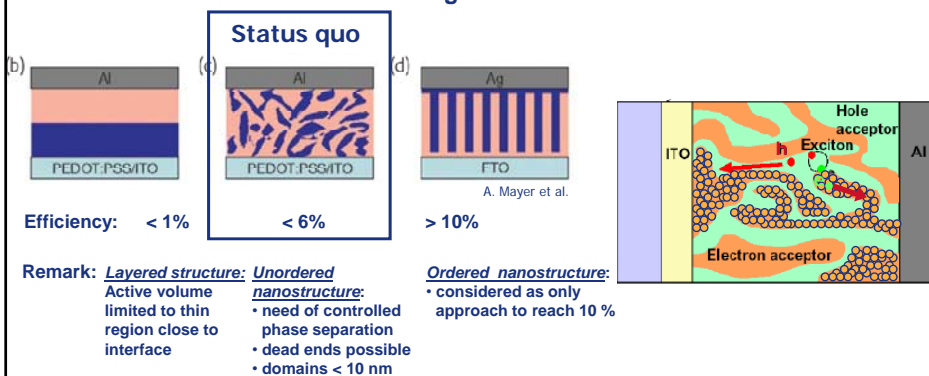
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Morphology of OPV cells

Low diffusion length and high excitons binding energy (Frenkel-type)

↳ Restrictions for cell design



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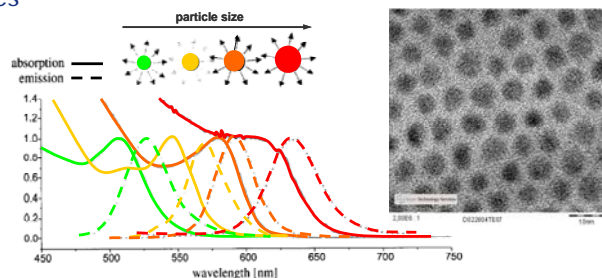
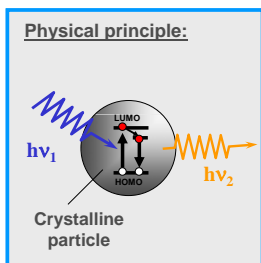
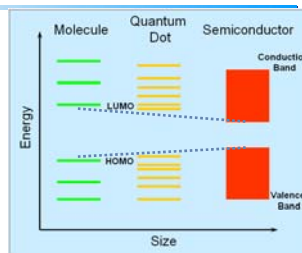
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n-type material: Quantum dots

Semiconductor nanoparticles

- Quantum dots are crystalline with a particle diameter between 1-10 nm
- Limited electron motion (quantum confinement) leads to altered optical, physical and chemical properties



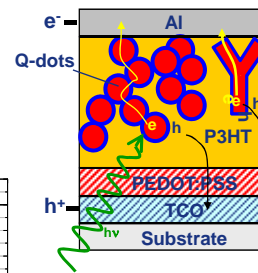
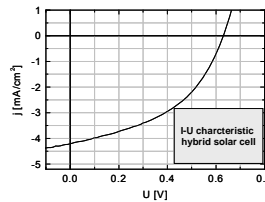
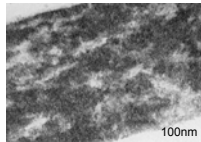
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Hybrid solar cells

- New approach with high potential
 - High e-mobility within *inorganic* semiconductors
 - High absorption efficiency of inorganic direct semiconductors
 - Shorter absorption length than with PCBM
 - Long range nanostructuring feasible with less contact points
 - Rods, needles,...
 - Branched nanoparticles
 - Possibility of predefined nanostructures



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Summary: Nanotech challenges

- **Large specific surface**
 - Risk of uncontrolled agglomeration due to high surface energy
 - High concentration of mostly necessary but unwanted stabilizing ligands
 - Control of surface properties (ligand exchange, adaption to matrix,...)
 - Potential of high reactivity
- **Nanostructure**
 - Favored morphology being highly effective for the designated application is often difficult to achieve and/or to maintain
- **Shelf life**
 - Risk of sedimentation
- **Costs**
 - Inexpensive access to desired nanomaterials

Control of these challenges is essential for the development of successful products

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Conclusion

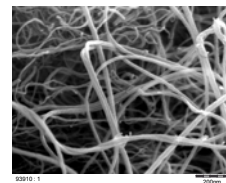
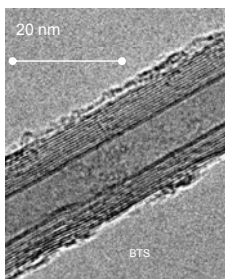
- **Nanotech can efficiently help to reduce CO₂-emission**
 - Nanocomposites for lightweight materials
 - Porous materials for thermal insulation
 - Semiconductor nanoparticles for photovoltaic systems
 - ...
- **Many challenges to be met with nanotechnology**
- **Challenges for the future**
 - in some cases progress is achieved during the past years
 - in some cases a (long) way to go
 - **Most problems will be solved in the future! (→ when?)**

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**Thank you
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