Bayer Technology Services

Nanotech for CO2-free energy generation

- Nano for efficiency -

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Bayer Working Group Nanotechnology

Working Group Nanotechnology

Fona, Berlin
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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 CO_2/km

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

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

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**





Nanotech to reduce CO_2-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

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
  - …

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 CO_2e-emissions (in 10 a)

Baymer®, Desmodur®

- Excellent insulation properties
- Less air leakages in buildings

1 kg Polyurethan saves 360 to 755 kg CO_2e-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

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

baytubes® dispersions and composites (passive)

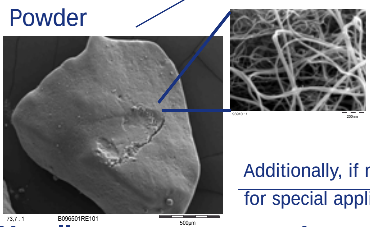
0,05 w.-% CNT

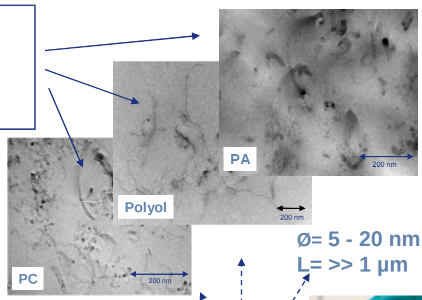
Complete dispersion in PC if CNT produced with specific catalyst and well defined processing parameters (T, t, hydrocarbons,...)

Techniques
- in-situ polymerisation
- Melt impregnation
- Solvent impregnation

Agglomerates of CNT (98% purity)

Powder





Ø= 5 - 20 nm
L= >> 1 µm

Additionally, if necessary for special applications

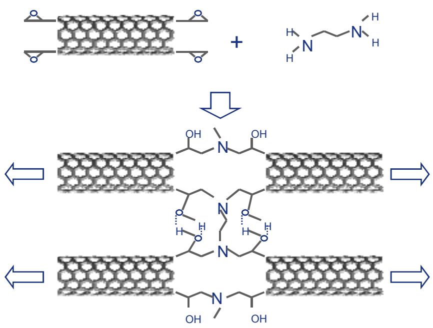
- High degree purification
- Disentangling
- Surface modification
- Chemical functionalization

Handle macro, get nano!

baytubes® dispersions and composites (active)

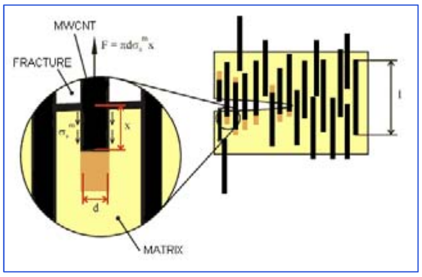
Functionalization of MWCNT (Baytubes®) in cooperation with Amroy Oy

HYBTONITE®



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

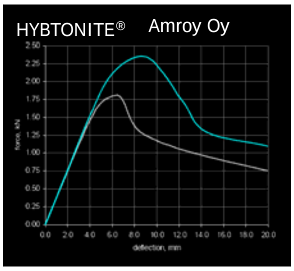
Fracture:



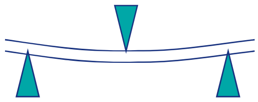
Hybride-MWCNT's as local reinforcement

baytubes® composites: reinforcement

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

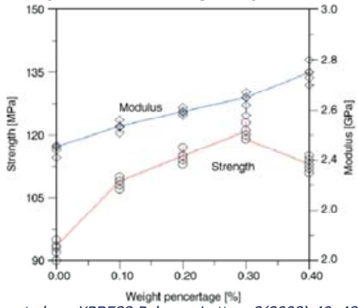


3p-bending tests of two similar carbon fibre laminates. Hybtonite® epoxy matrix (upper curve), SP Prime20 epoxy matrix (lower).



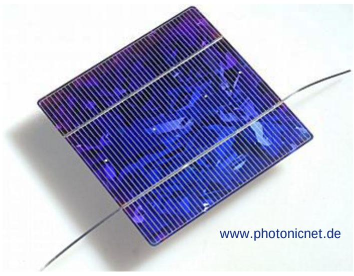
HYBTONITE technology with improved properties:

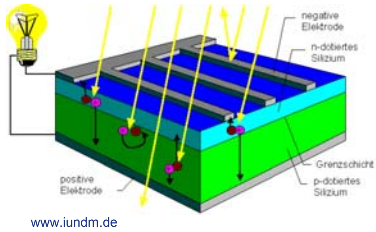
- Impact strength by 20-30 %
- Fatigue by 50-200 %
- Lower the weight by 10-30 %
- Compression strength by 10-20 %



Zhou et al. – eXPRESS Polymer Letters 2(2008) 40–48

1st Gen Solar cells: c-silicon





Penetration depth	Absorbed sunlight
0,1 µm	6 %
0,7 µm	17 %
150 µm	72 %
300 µm	76%

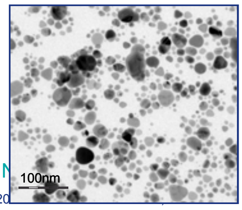
Classical c- or mc-silicon cells need **thick, high-quality Si-wafers** (> 100 µm) for effective sunlight absorption and long exciton diffusion lengths to interface

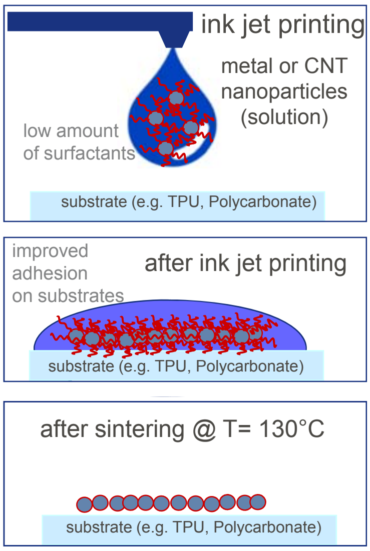
Established and nanotechnology is not involved, ...

... except the fingergrid electrodes

Conductive Microstructures

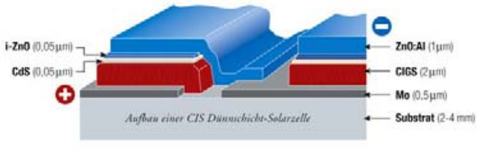
- **Approach**
  - Production of a dispersion of suitable particles
    - Synthesis of nano silver (→ BayInk®)
    - Dispersion of MWCNT(→ Baytubes®)
  - Printing on flexible substrates
    - Inkjet printing (down to 30 µm)
    - Screen-printing
  - Sintering process
    - Low sintering temperature (< 130 °C)
    - 155 mΩ/□ (2 µm thick)
    - **6•10^6 S/m (10 % of bulk silver)**

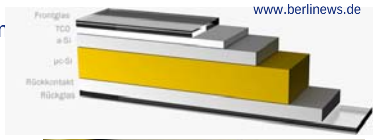




2nd Gen Solar Cells: Thin Film PV (CIGS, a-, µ-Si,…)

www.gotsolar.com





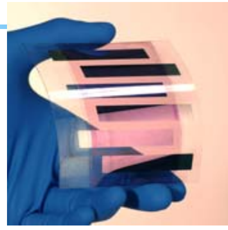
www.berlinews.de

- Due to high absorption yield much thinner cells (< 5 µm) 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
  - ↳ New approach e.g. by Nanosolar
    → nanoparticle ink (printing + annealing)

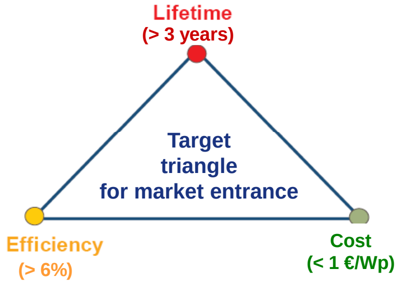
➡ **Nanotechnology for cheaper processing**

www.nanosolar.com

3rd Gen solar cells: OPV



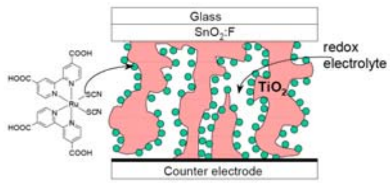
- Inexpensive energy source
- Flexibel substrates
- Roll-to-roll processing
- Entrance market: “mobile” applications (off-grid)
- Minimum targets:

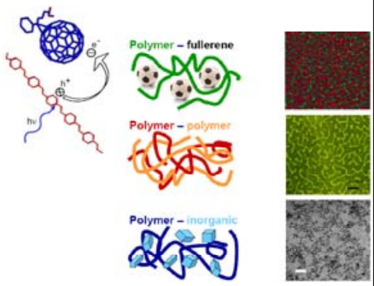


3rd Gen solar cells: OPV

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, TiO_2,…)



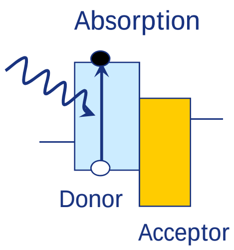


Janssen et al.

OPV and nanotech

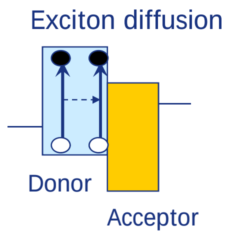
- **Common feature for OPV: Low exciton diffusion length < 10 nm**
- **<u>Consequence</u>: Nanotechnology is essential for OPV**
  - Control of structure and morphology on the nanoscale
  - Large scale multilayer system with thicknesses of ~ 100 nm

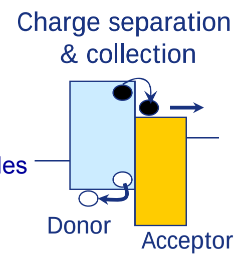
- **Requirements for material and morphology**
  - *<u>Material</u>*: High absorption (> 10^5 cm^{-1})
    - Polymers and direct semiconductors are effective absorbers with absorption lengths of ~ 100 nm



OPV and nanotech

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



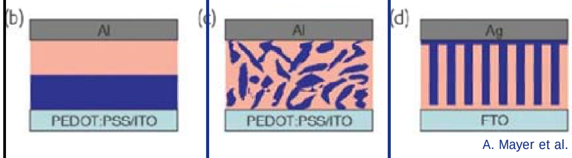


Morphology of OPV cells

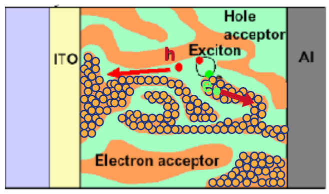
Low diffusion length and high excitons binding energy (Frenkel-type)

↳ Restrictions for cell design

Status quo



A. Mayer et al.



Efficiency: < 1% | < 6% | > 10%

Remark:

Layered structure: **Active volume limited to thin region close to interface**

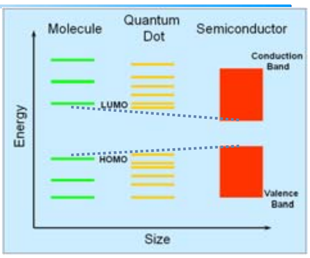
Unordered nanostructure:
- **need of controlled phase separation**
- **dead ends possible**
- **domains < 10 nm**

Ordered nanostructure:
- **considered as only approach to reach 10 %**

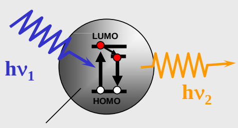
n-type material: Quantum dots

Semiconductor nanoparticles

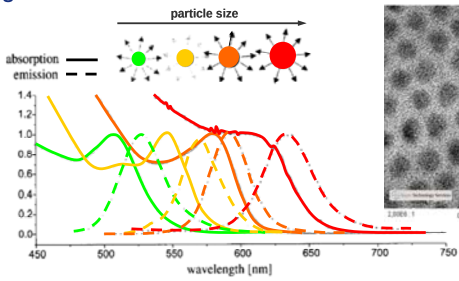
- Quantum dots are crystalline with a particle diameter between 1-10 nm
- Limited electron motion (quantum confinement) leads to altered optical, physical and chemical properties

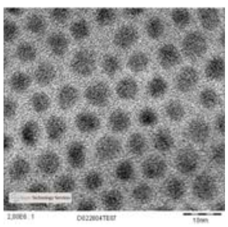


Physical principle:



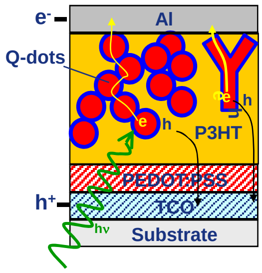
Crystalline particle

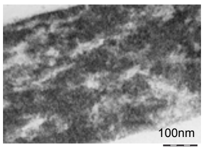


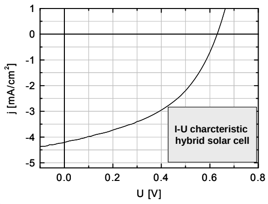


Hybrid solar cells

- 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







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

Conclusion

- **Nanotech can efficiently help to reduce CO_2-emission**
  - Nanocomposits 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?)**

Thank you
for your attention!