can

Centrum für Angewandte Nanotechnologie

Nanomaterials for energy conversion and energy harvesting

Dr. Jan Dorn

CAN GmbH, Hamburg

NCCR MUST Workshop

13.06.2012

Outline

1. Company Profile
2. CAN GmbH activities in the field of nanotechnology
    a) Synthetic aspects
    b) Particle Systems
3. Application of nanoparticles in 3rd generation photovoltaics
4. Summary
5. Outlook

CAN GmbH

Business Model:	Public Private Partnership (PPP)
Founded:	November 2005
Location:	Hamburg
Staff:	30 (today)
Vol. of Sales:	1.5Mio €
Associates:	Verein zur Förderung der Nanotechnologie e.V. (65,2 %) City of Hamburg (24,8 %) University of Hamburg (10 %)
Chairman of the board:	Prof. Dr. Klaus-Peter Wittern
CTO:	Prof. Dr. Horst Weller
COO/CFO :	Dr. Frank Schröder-Oeynhausen

CAN GmbH: Overview

Business Model:

- „Technology Transfer in the Lab“
  - Standardization
  - Upscaling
- Contract Research for Industry
- Third party funded research
- Sale of selected nanoparticle species (side offs)

- Technology: Nanoparticle systems
- Target Market: Life Science, Optoelectronics, …

CAN GmbH: Fields of expertise

Nanoparticle Synthesis

Energy

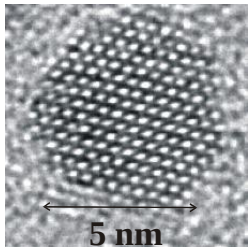
Life Science

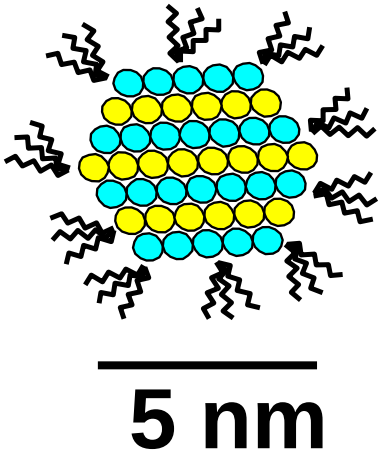
Home & Personal Care

Inorganic Nanoparticles

- Nanoparticles consists of an inorganic core (metal, semiconductor, insulator, magnetic)
- Particle synthesis in colloidal solution (2-150 nm)
- In a 5 nm particle ~ 20% of the atoms are at the surface!
- (Post-synthetic) surface modification allows various applications

TEM-Aufnahme
eines Nanokristalls





CANdot® Batch Synthesis

Advantages

- Universal applicability
- Well established
- Wide temperature range
- flexible reaction time

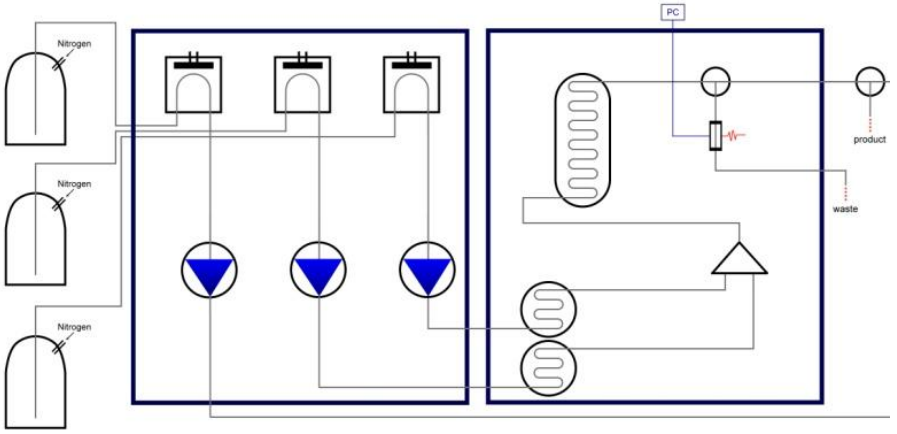
Disadvantages

- Limited reproducibility
- Small batch size (typically 100 mg)
- Time and cost consuming
- High chemical consumption
- “feeling” needed

CANdot® Continuos Flow Synthesis

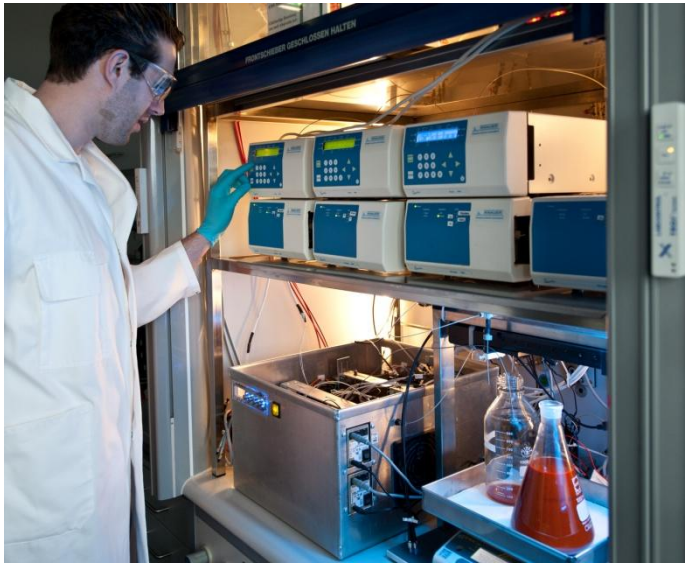
Advantages

- Higher production capacity 10 g/day
- High reproducibility
- Efficient use of chemicals
- Increased lab safety!
- Lower costs through automatization
- Screening and optimization
- Parallelization



Disadvantages

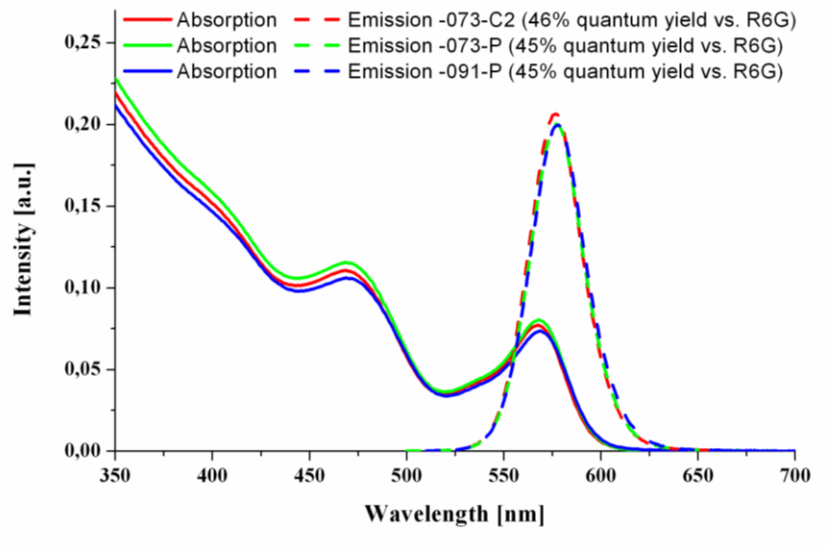
- expensive equipment
- development of suitable synthetic route



CANdot® Series A: Core/Shell Quantum Dots

Properties

- II-VI-Semiconductors
- Emission maxima 500 to 625 nm
- High quantum yield > 40%
- High significance (0,1%)
- Polar and non-polar dispersions
- Improved shell structure
- Sale



Applications

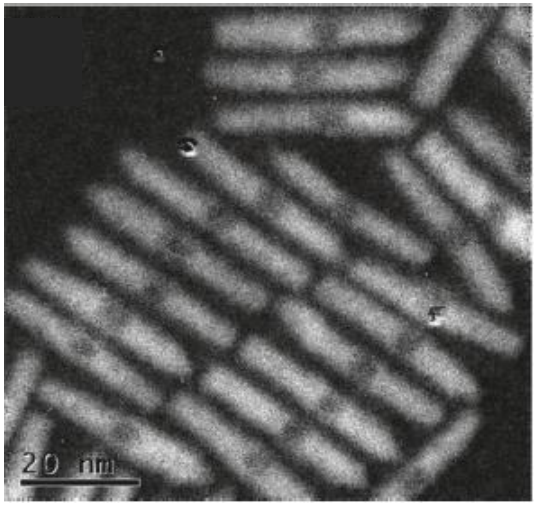
- Biomedical markers
- QD LED and White light-LEDs
- Absorber in Solar Cells

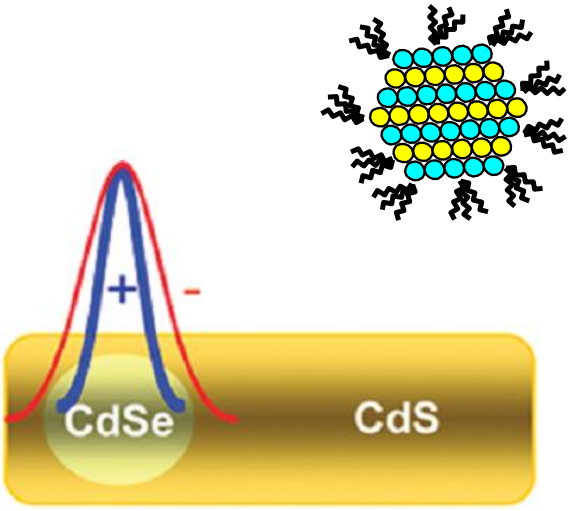
CANdot® Series Outlook CdSe/CdS dot-rods

- Advanced morphologies in continuous flow
  - Dot-in-Rod,
  - Rod-in-Rod,
- Emission maxima 500 to 625 nm
- High quantum yield > 80%
- Long fluorescence lifetime
- Polar and non-polar dispersions
- Improved shell structure

Applications

- Biomarkers

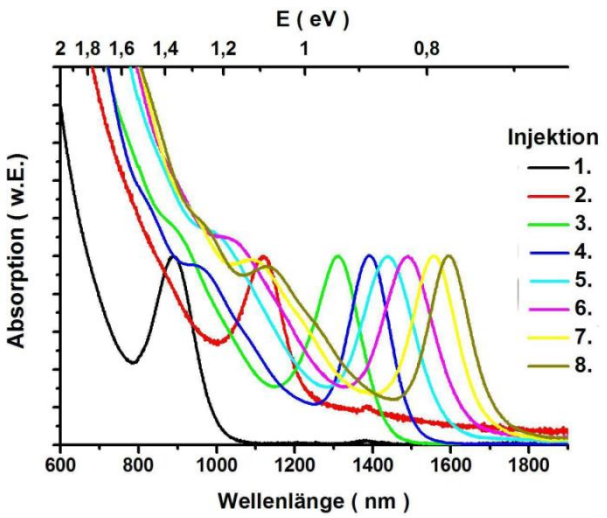




CANdot® Series C: PbS

Properties

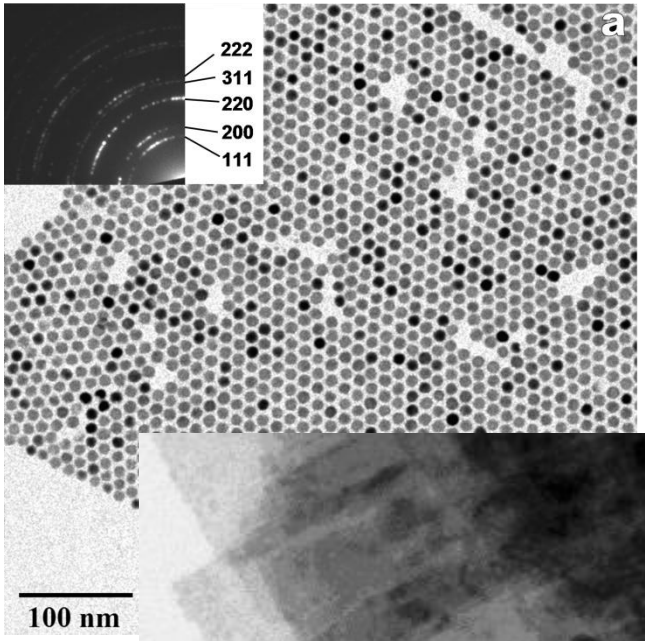
- Bulk bandgap 0,37eV
- Band gap tunability up to 1,4 eV
- IR absorption max: 900 to ~1600 nm
- No passivation shell needed
- High reproducibility due to continuous flow synthesis

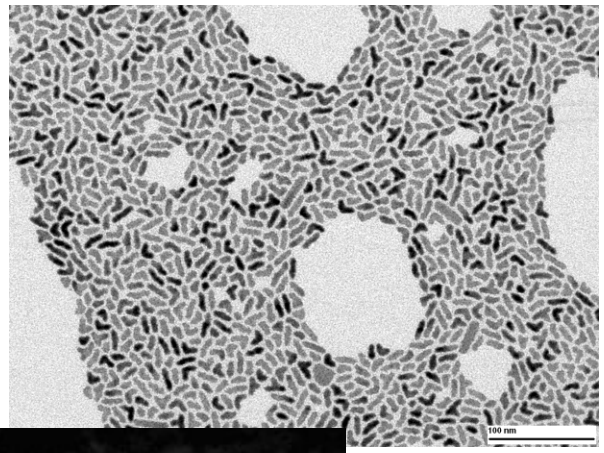


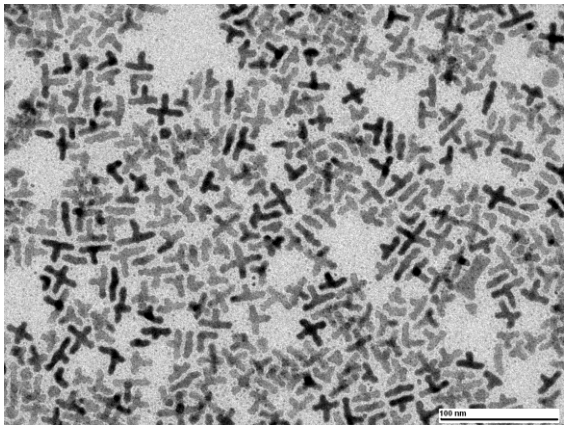
Applications

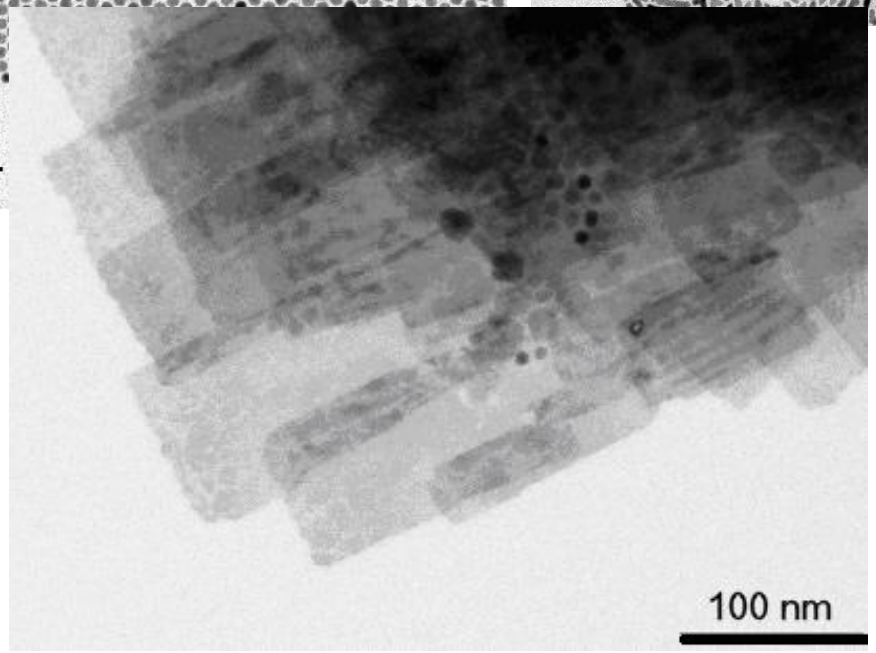
- Absorber in solar cells
- IR Photodiodes
- IR LED

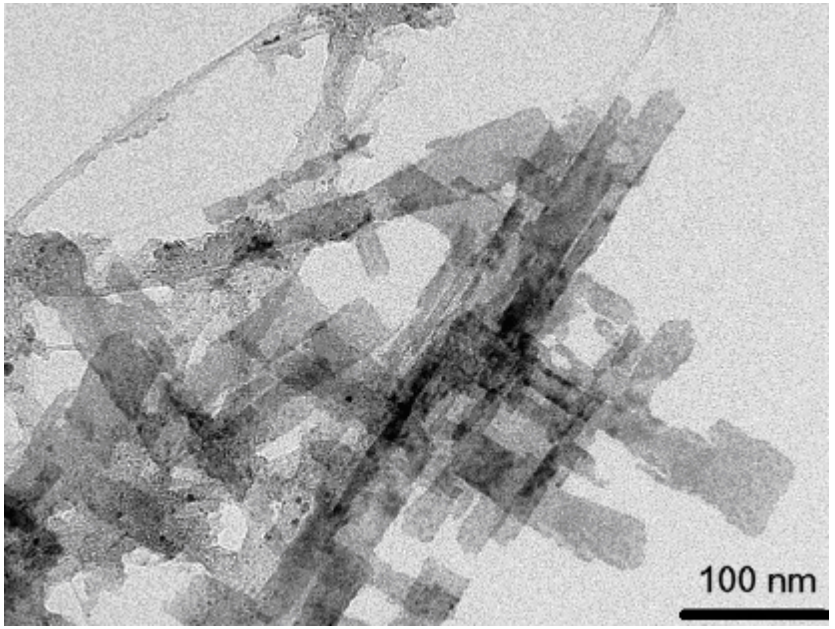
Morphological diversity of PbS











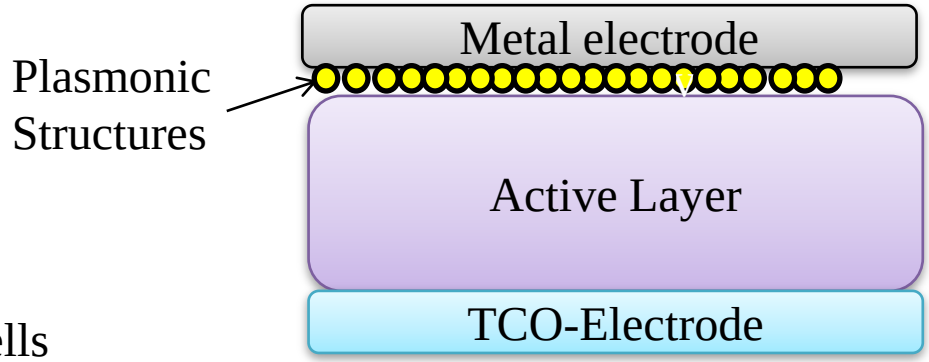
CANdot® Series G: Gold nanoparticles

Properties

- Size 10 to 120 nm
- Plasmonic resonance tuning (515-620nm)
- Spheres or rodlike morphologies
- Dispersable in polar and non-polar solvents
- Upscaling in progress

Applications

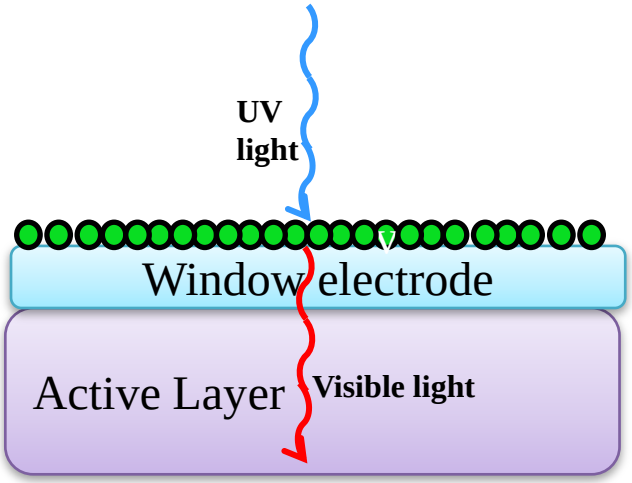
- Biomarker
- Light management in solar cells



CANdot® Series X: Rare earth doped nanoparticles

Properties

- green: $LaPO_4$:X, yellow: $BaSO_4$:X, red: YVO_4:X
- Rare earth metals (X = Eu, Ce, Dy,…)
- Excitation with UV light
- Colorless and transparent under visible light
- Chemical and temperature stability (Up to 600°C)



Applications

- UV-Converter
- Security label

CAN GmbH: Fields of expertise

Synthesis

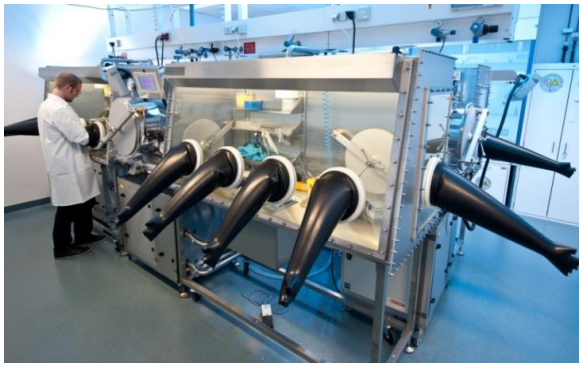
Energy

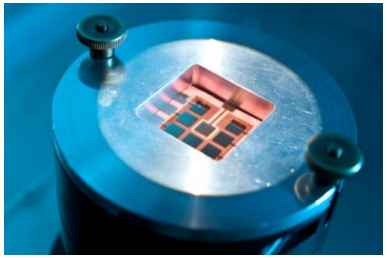
Life Science

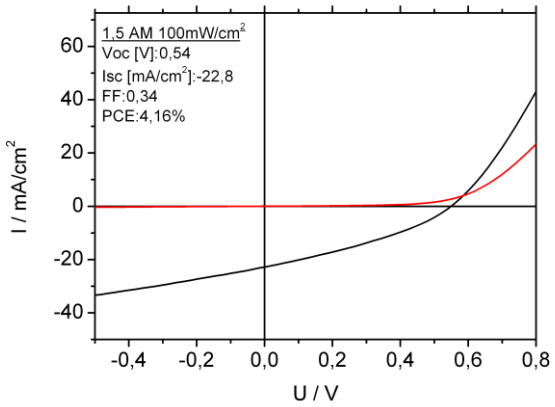
Home & Personal Care

Basic PV Preparation and Characterization

- Glovebox system
- Preparation and characterization under inert gas
- SEM incl. Focused Ion Beam
- HR-TEM
- X-ray characterization (incl. synchrotron radiation @ DESY)
- Optical spectroscopy



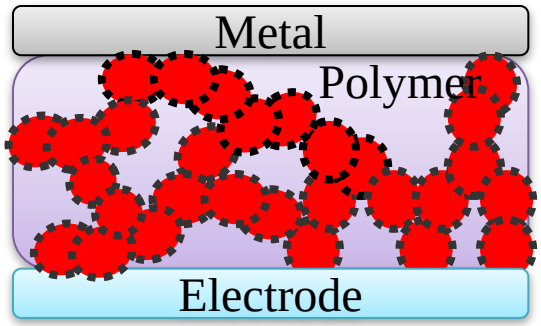




"Record cell"
ITO/ZnO/PbS:EDT/Au

Semiconductor Nanocrystals in Photovoltaics

Nanocrystal-Polymer Hybrid Solar Cells



Advantages

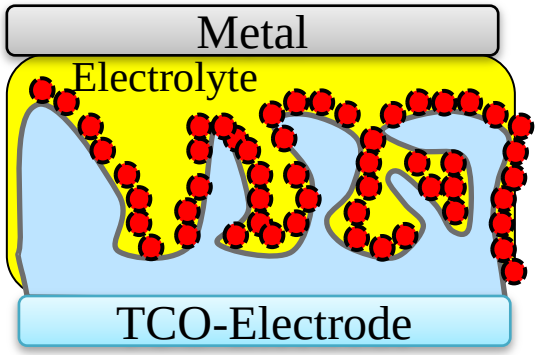
- Active layer via self-assembly

Disadvantages

- Morphology control
- HTL-Polymer
- High exciton binding energies

2002: 1,7% CdSe Nanorod
Science 2002, 295, 5564, 2425-2427
20 10: 3,1% CdSe Tetrapods
Nano Lett. 2010, 10, 1, 239–242

Quantum Dot-Sensitized Cells



Advantage:

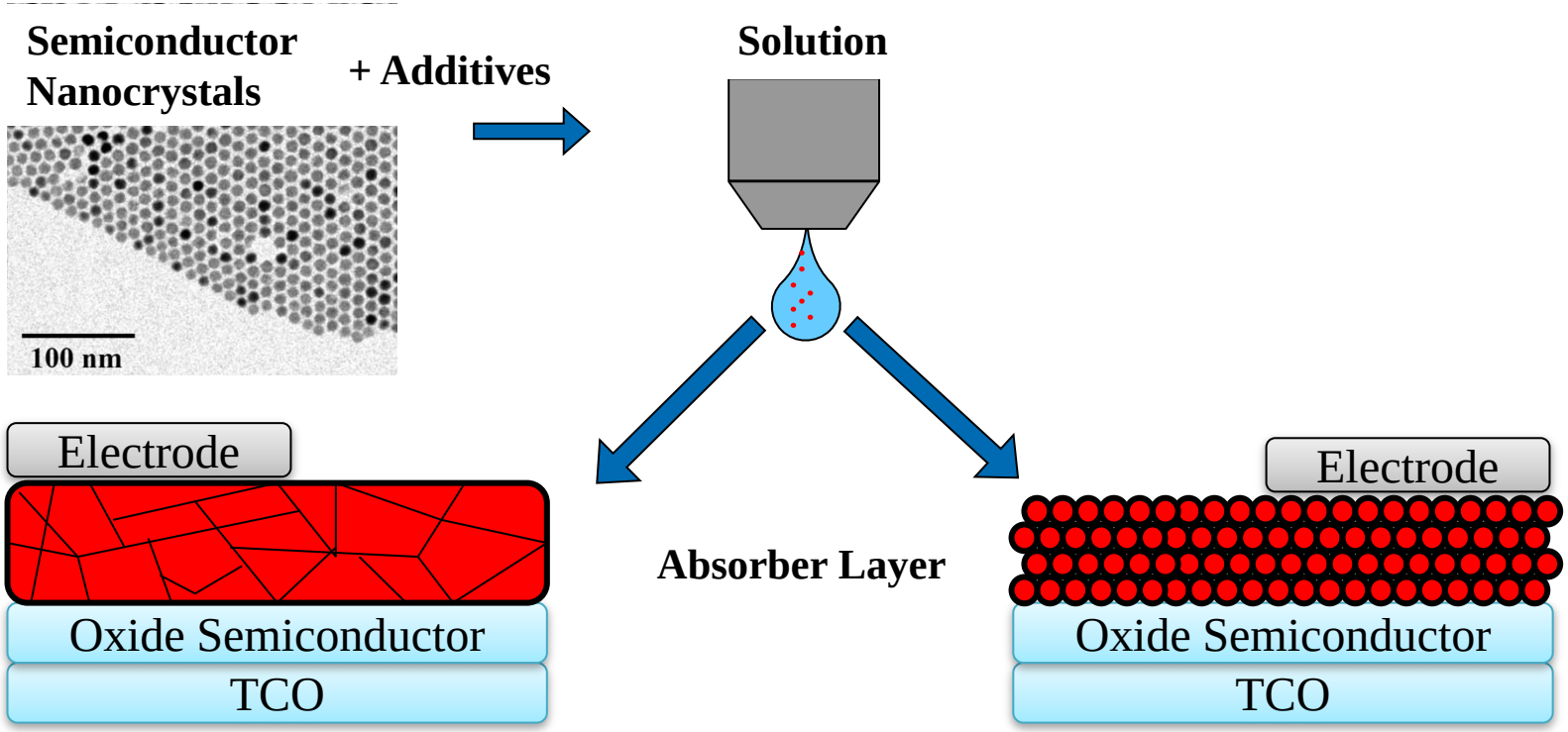
- Increased IR-sensitivity (PbS-QDs)

Disadvantage:

- High QD-coverage of TiO_2 difficult
- Surface passivation of NP against reactive electrolyte

2011: 12,3% Co II/III electrolyte
Science 2011,334, 6056, 629-634

Semiconductor Nanocrystal Photovoltaics



- Thin film solar cells
- Compact µ-crystalline film
- $CuInGa(S,Se)_4$ –NP as Precursor
- η_{rec} = 7-8%

„All-Nanocrystal“ Solar Cells

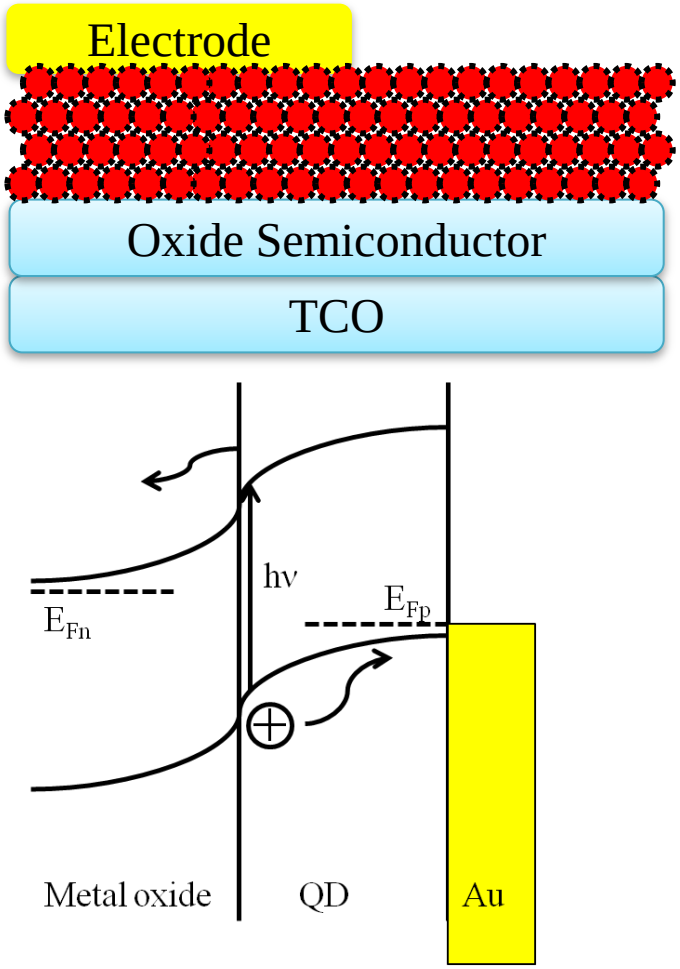
- Nanoparticular film
- Chalcogenides (PbS, PbSe)

Third Generation Nanocrystal Photovoltaics

- Solution processing
- Band gap tuning by nanoparticle size (PbS-nanocrystals)
- Good charge separation (high ε_{eff})
- p-n-Junction with distinct layers
- High carrier mobility
  - Reduce trap states
  - Direct film morphology

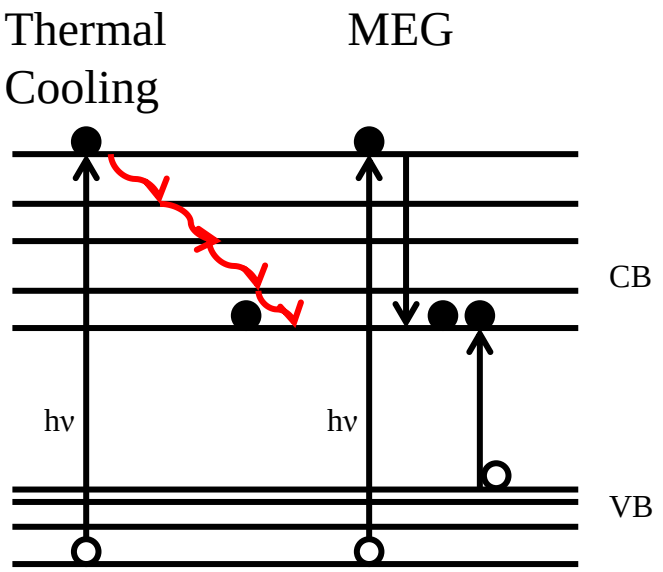
→ Surface chemistry control!!!

→ Screening with continuous flow synthesis



Multiple Exciton Generation (MEG)

- Two excitons from one photon
- Enhanced in quantified systems
  - need for nanoparticles
- Dependent on DOS (less “cooling” channels)
- Single Junction Limit: η=33%
- Multiple Exciton Generation (MEG) theoretically allows η=44%



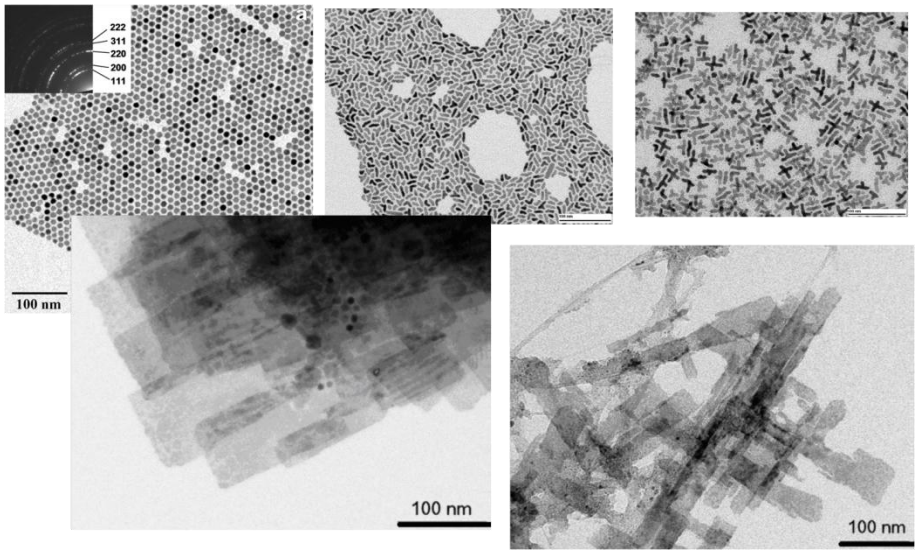
External Quantum Efficiency
114 %
in a PV device (ITO/ZnO/PbSe/Au)

M. Beard, A. Nozik, Science (2011) 334, 6062 ,1530-1533

Enhancing MEG

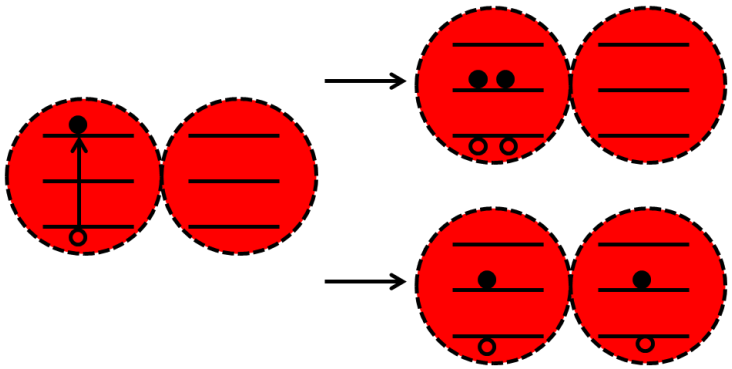
- MEG-Threshold at > $3E_g$ for PbSe nanocrystals (dots)
- MEG-Threshold at ~ 2,2 E_g for PbSe nanorods

→ Morphology screening via continuous flow synthesis



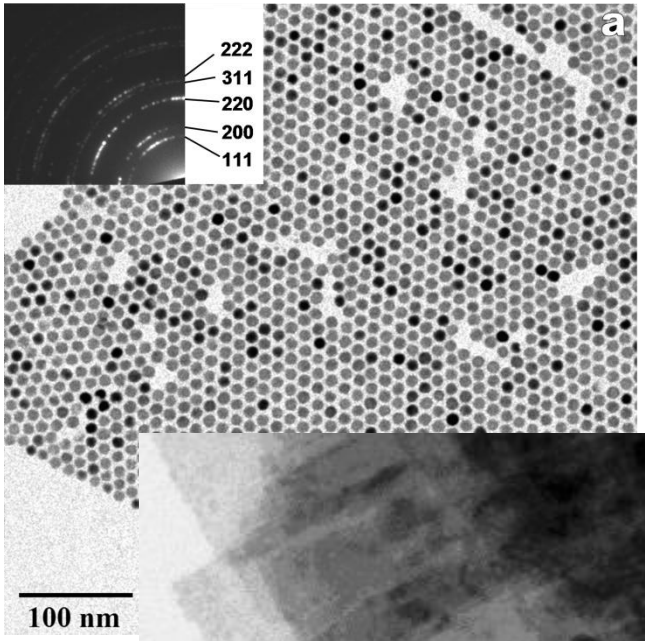
- Various MEG-mechanisms
- Strong coupling with inter-NP-distance <1 nm

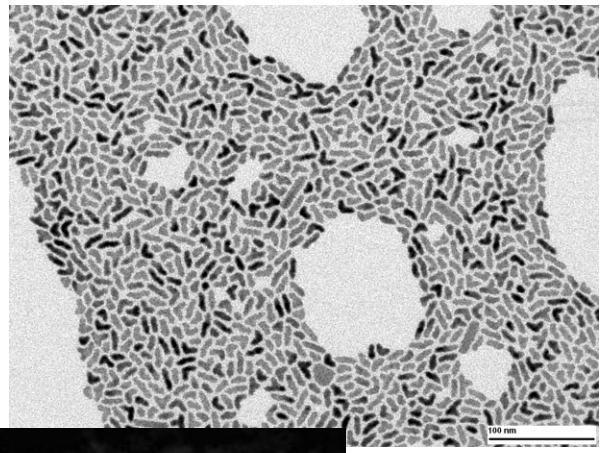
→ Surface chemistry control

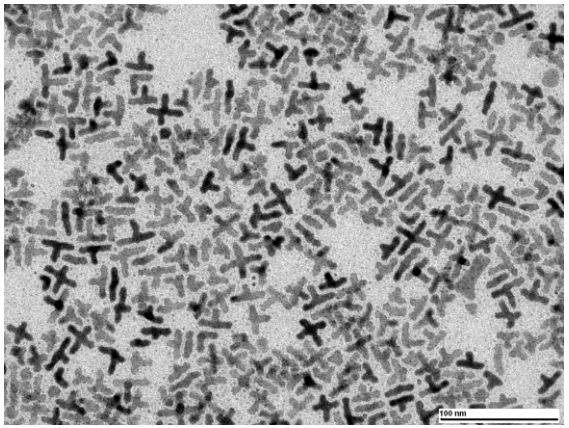


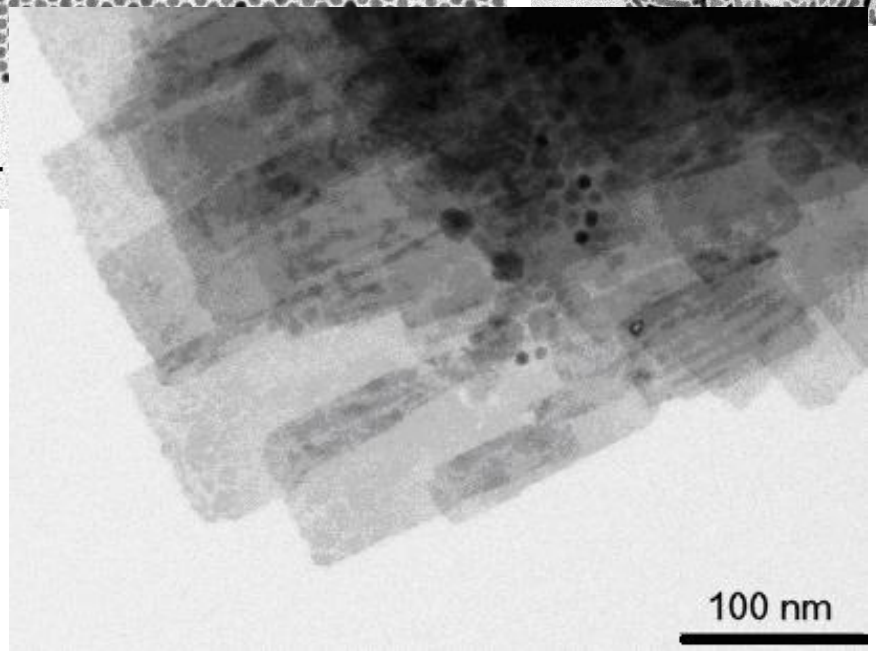
Trinh et al. Nature Photonics 2012, 6, 316-321

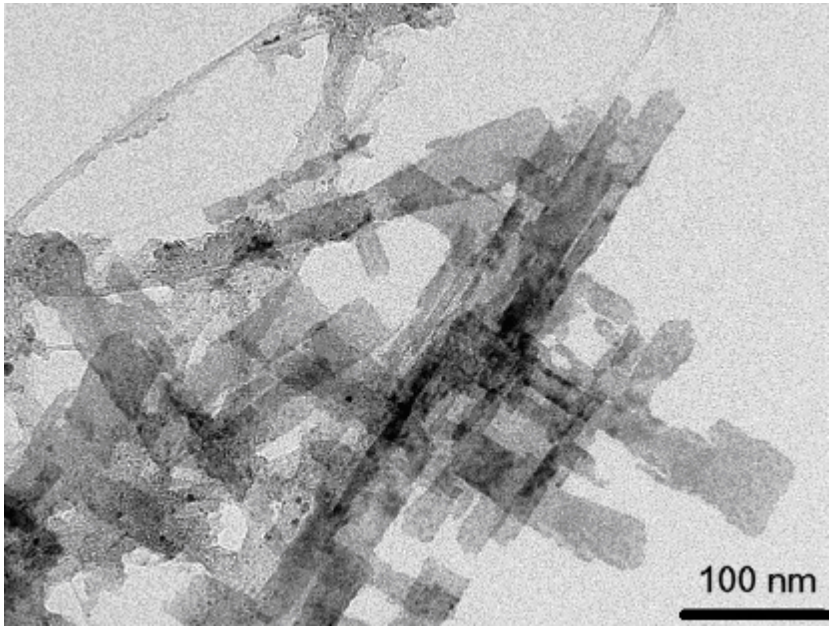
Morphological diversity of PbS





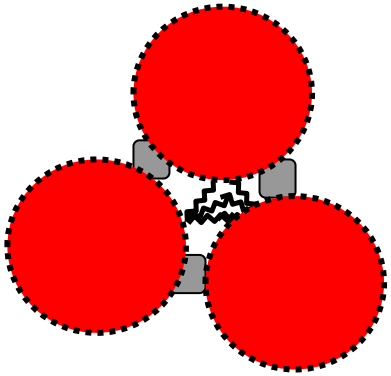






Summary

- Size matters!!!
- Nanomaterials can have a significant impact on photovoltaics
- If size matters → SURFACE MATTERS!!
- For 3rd generation photovoltaic systems based on nanotechnology it surface chemistry control is of greatest importance!

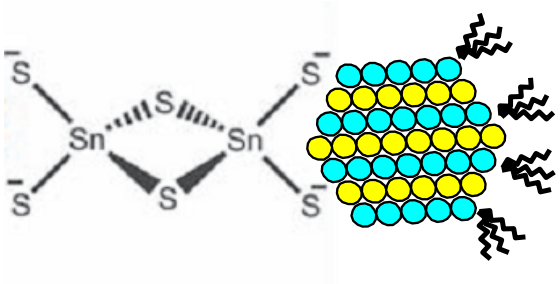


- Continuous flow synthesis is a promising tool for nanomaterials synthesis

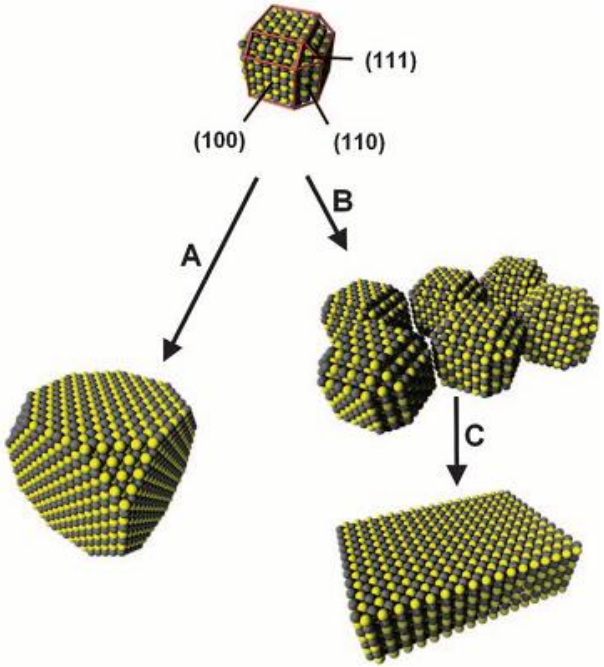
2008 η_{rec} = 1,1 % ACS Nano 2008, 2, 5, 833–840
2011 η_{rec} = 6,0% Nature Materials 2011, 10, 765–771

Outlook

- New ligand systems
- New material systems (e.g. PbTe or Semiconductor Alloys)
- Improved material morphologies like plateletts/sheets
- Improved device concepts



Talapin, et al., Science, **324**, 1417 (2009).



Weller, et al. Science, **329**, 550 (2010)

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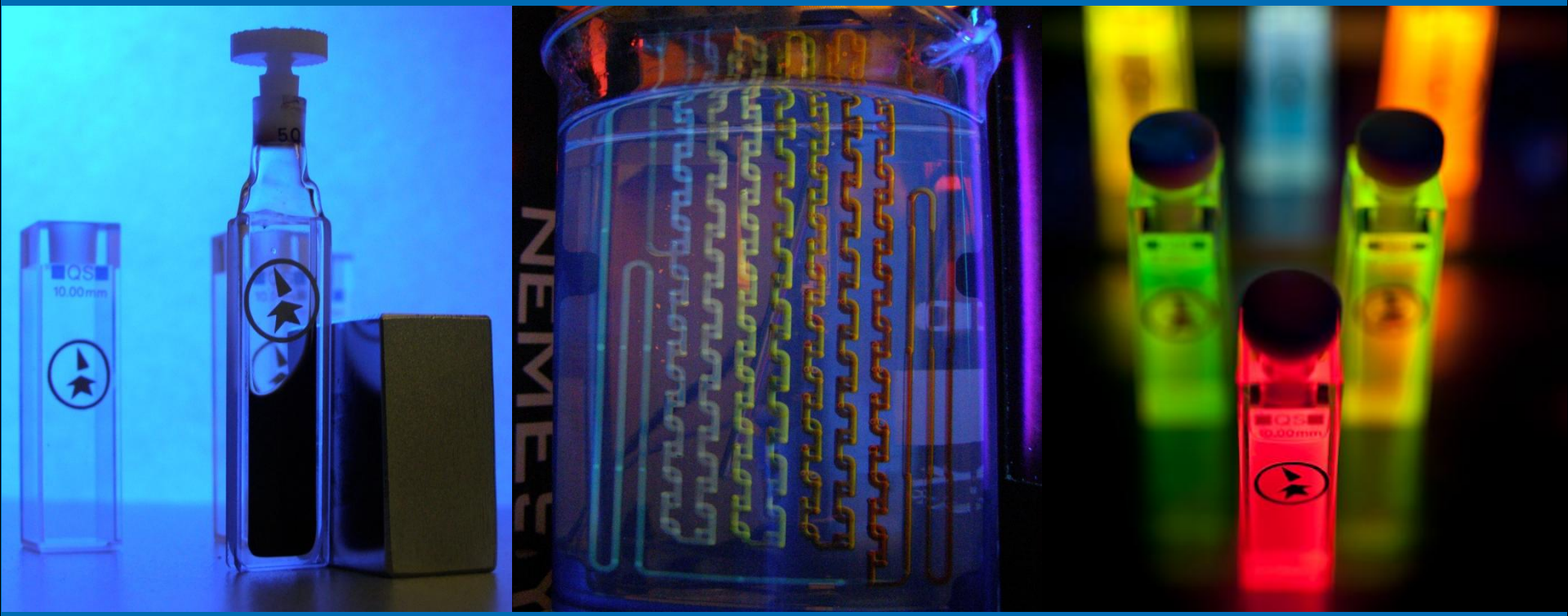

Thank you for your attention!