A Novel Biosensor for Water Quality Monitoring combines DNA Origami and Quantum Technology

Project GREENER

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GREENER– Consortium

- Title: "*Single Photon source and detector based on novel materials for the detection of endocrine disruptors*"

GER: *TUC (CO)*, *ENAS, IFU*, **SPA**: *CICB*, **FR**: *AUREA*, **IT**: *SJ, WH, TC*

GREENER – Motivation

- Health risks due to contamination (EDC) of water are a major problem
- Even extremely low concentrations of contaminants can have an impact on humans and animals
- Problem: Contaminants are not measurable on-site
- Target: On-site measuring of extremely low concentrations of hormones or hormone-like substances in water for fisheries and aquaponics
- Development of a **new type of *single photon spectrometer***
  - Compact
  - Robust
  - Modular (source, detector, flow Cell with sample)

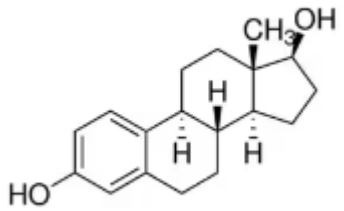
https://albert-schweitzer-stiftung.de/wassertiere/fische-aquakultur

https://www.swd-ag.de/magazin/was-ist-aquaponik/

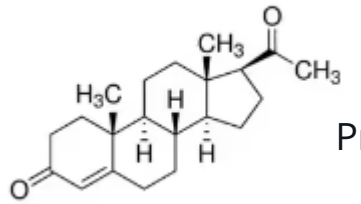
GREENER – Motivation (EDC target substances)

- Focusing on:
  - 4,4'-Isopropylidendiphenol (Bisphenol A)
  - β-Estradiol
  - Estriol
  - Progesteron
  - 17α-Ethynylestradiol
  - 3-Indolacetic acid (IAA)
  - Norethisteron
- NIR Reference measurements

Bisphenol A

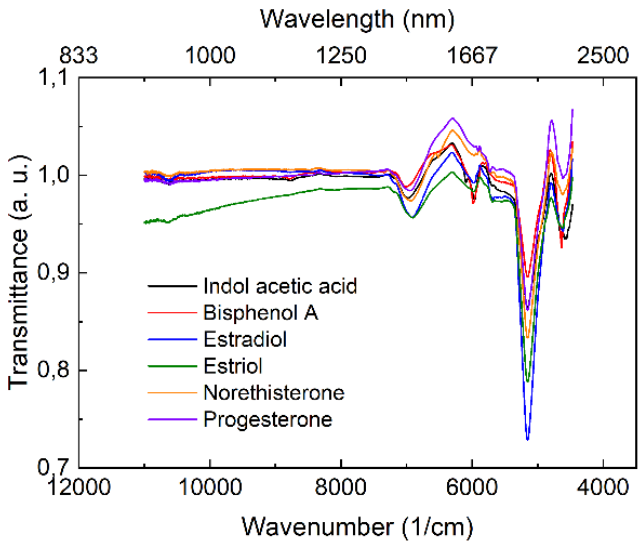


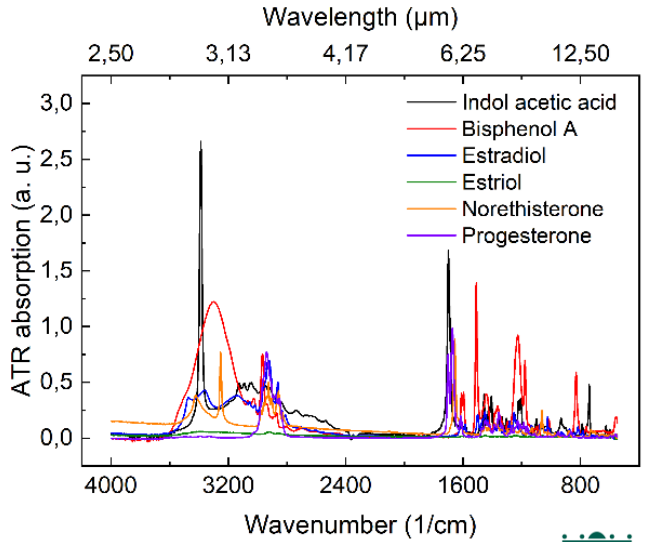
β-Estradiol



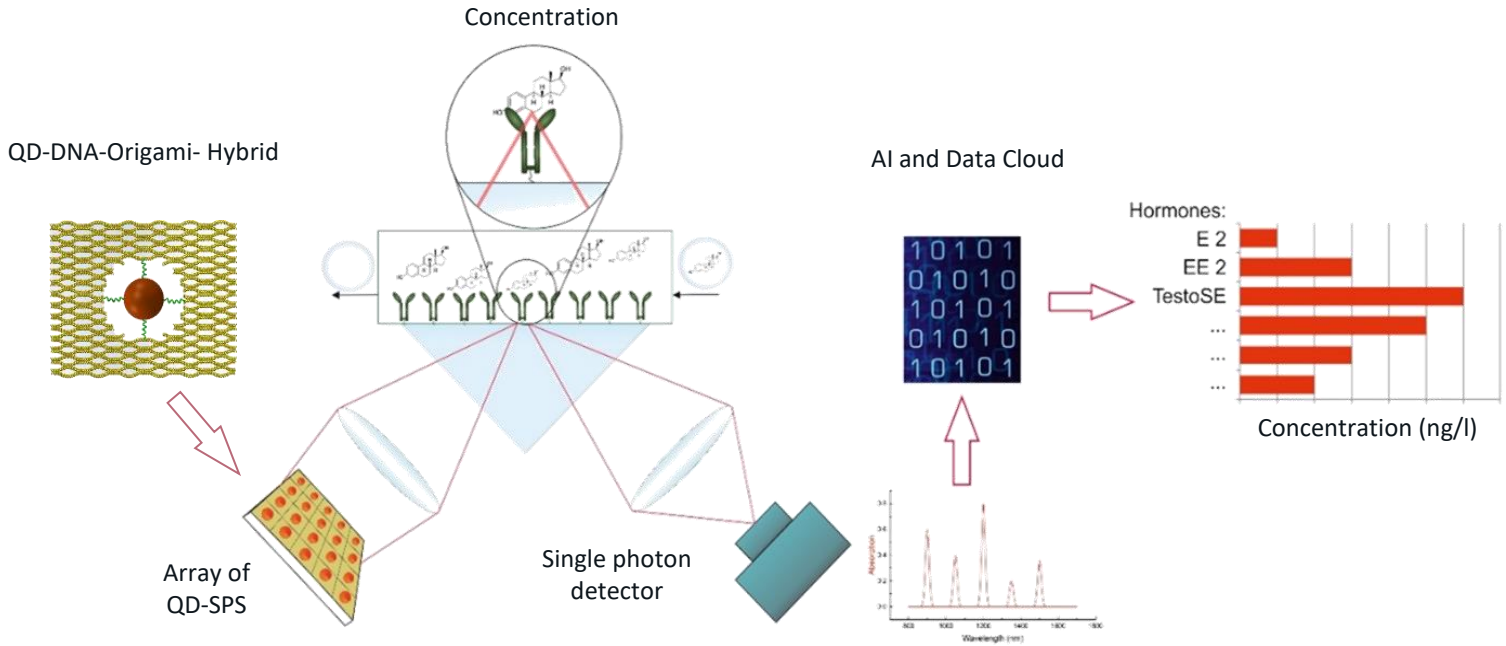
Progesteron

NIR and MIR spectra,
substances dissolved in methanol @ 20mg/ml,
recorded with FTIR spectrometer VERTEX70



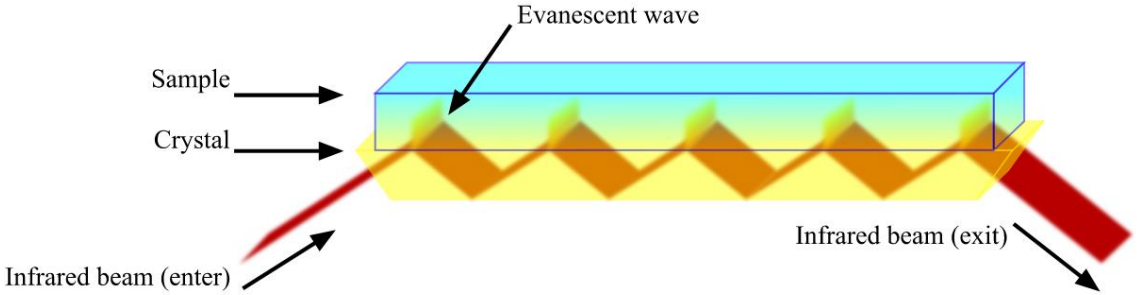


- Spectrometer and its Components
  - ***Single Photon Source*** (SPS): Array of SPS with different wavelengths → spectrum
  - ***Flow cell***: Pre-concentration of target substances
  - ***Single Photon Detector*** (SPD): Improved single-photon detector with high efficiency in SWIR
  - ***AI and Data cloud***: AI data analysis for improved selectivity
  - ***Spectrometer set-up***: includes components, optical path adjustment, electronics

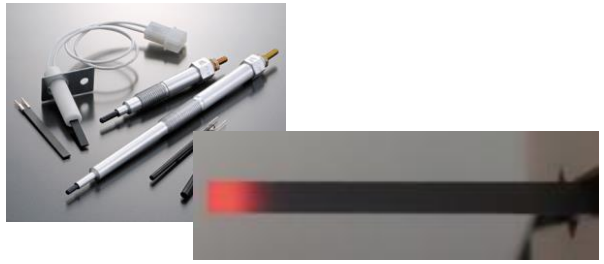


GREENER - Single Photon Source

- Using ***attenuated total reflection (ATR)*** as measuring technique in conjunction with infrared spectroscopy
- Classical light sources (thermal, coherent)
  - High photon noise
  - Limits the low absorption measurements
- Using ***single photon source*** as light source combined with ***single photon detector*** with high quantum yield
  - High noise reduction
  - Measurement of substances in the ng/L range possible
- Development of Single Photon Source
  - Synthesis of new, green NIR-QDs integrated in DNA origami
  - Development and integration in LED-Layer stack



https://www.leuchtmittelmarkt.com



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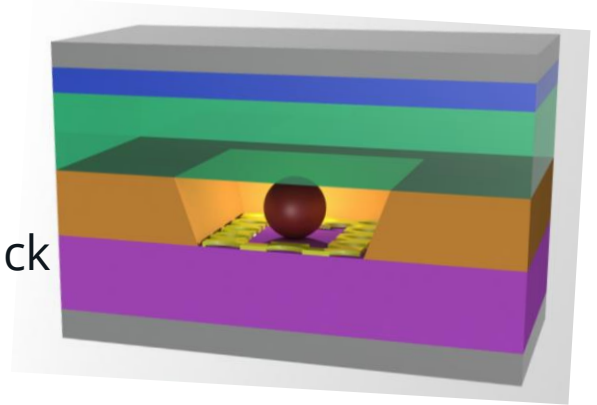

Brahim Lounis and Michel Orrit, *Rep. Prog. Phys.* **68,** 1129 (2005).

Ratio of variances:

$$\frac{\Delta T_{SP}^2}{\Delta T_C^2} = 1 - 2x\frac{T}{1+T}$$

if x~1 and T~1:
→ perfect noise canceling

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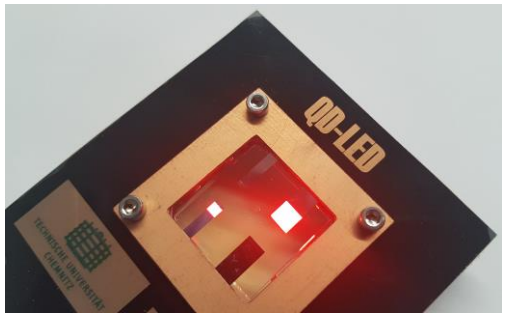
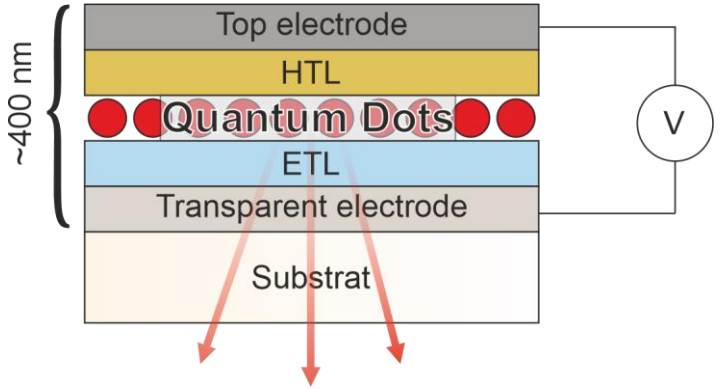
QD-LEDs combination with beam shaping elements



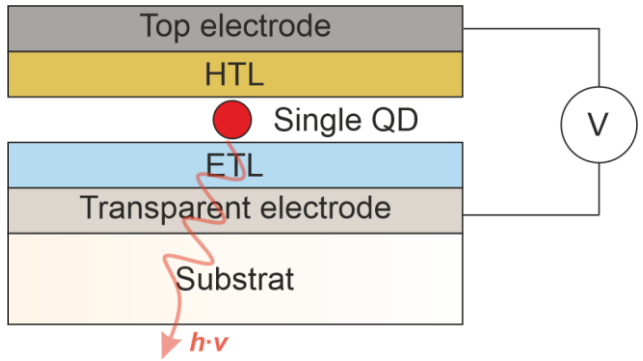


QD-LED

- Thin-film layer stack
- Components: Electrodes, HTL, ETL, QDs
- Injection of charge carriers causes radiative recombination

→ many photons emitted into half-space

Contacting of a single quantum dot using the QD-LED layer stack to realize a single photon source

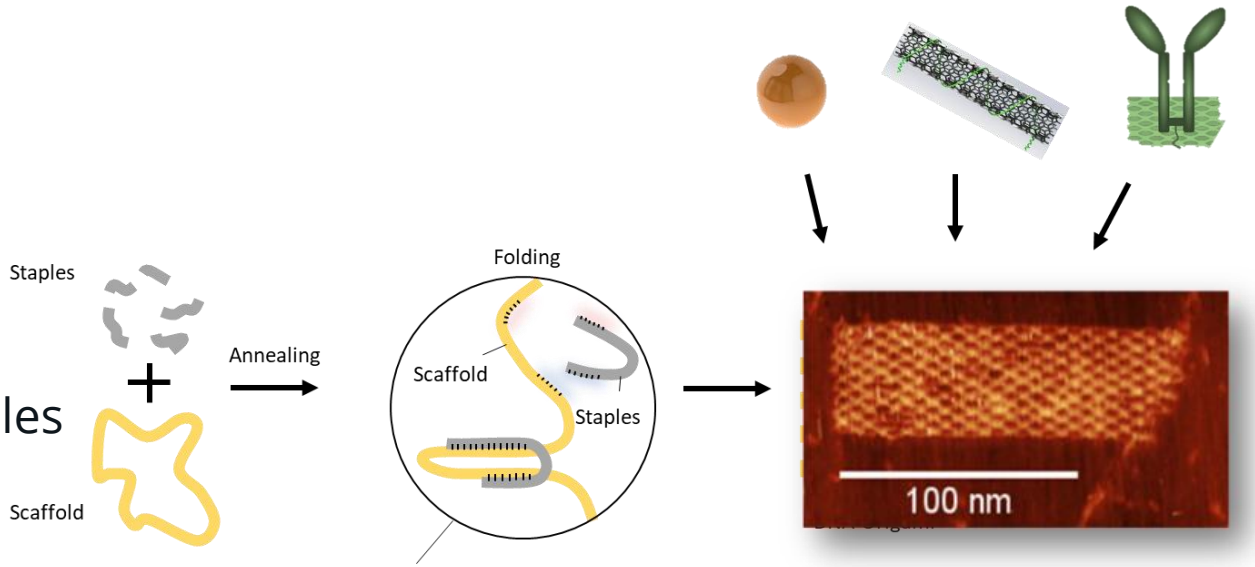


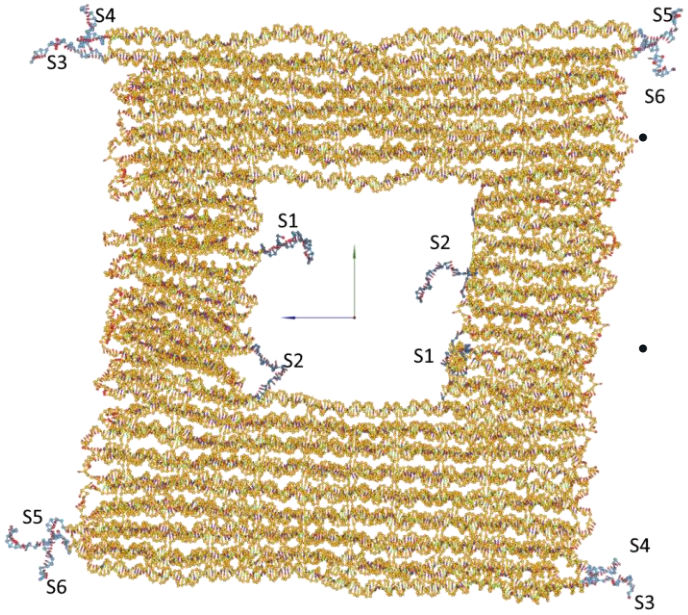
Single Photon Source

- Contacting of one Quantum Dot
- Using non-toxic, environmental friendly QD in SWIR range

→ single photon emission

- Realizing precise localization of Qdot emitters
  → bottom-up DNA Origami Technology
  - Folding of circular scaffold strand by shorter staple strands
  - Staples overhang allows selective binding
    → Quantum Dots
  - Due to the well defined position of each stables
    → nano bread board
  - Resolution of 2,5 – 5 nm





- Immobilisation-Sequences (S3-S6)
  S3: TGCGATAATC-AGACTTTTTCATG
  S4: ACGGTCGATA-GAGCGGGAGCTAAAC
  S5: GTTTGACCATTAGA-AGTAGTAGAC
  S6: ACGAGCTACC-TACATTTCGCAAA
- NP-Functionalisation-Sequences (S1 & S2)
  S1 (Top Left): CATGCATCAGGGTACTACGACGT-TGGGCGCATCAAACCC
  S1 (Bottom Right): CATGCATCAGGGTACTACGACGT-TTACCATTAGCAA
  S2 (Top Right): AAAGACAAAAGGG-CGATCGATCTCGAACGTACGACA
  S2 (Bottom Left): TTTAACCAATAG-CGATCTGCTCGAACGTACGACA

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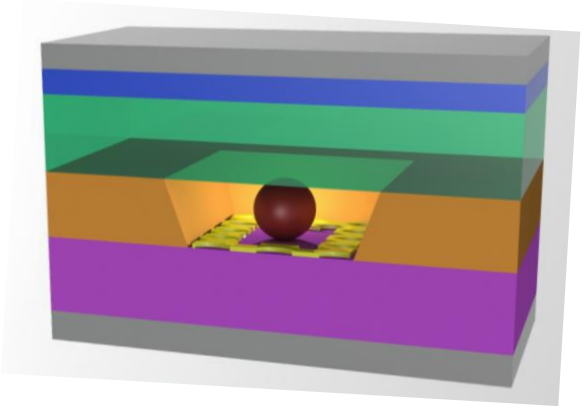
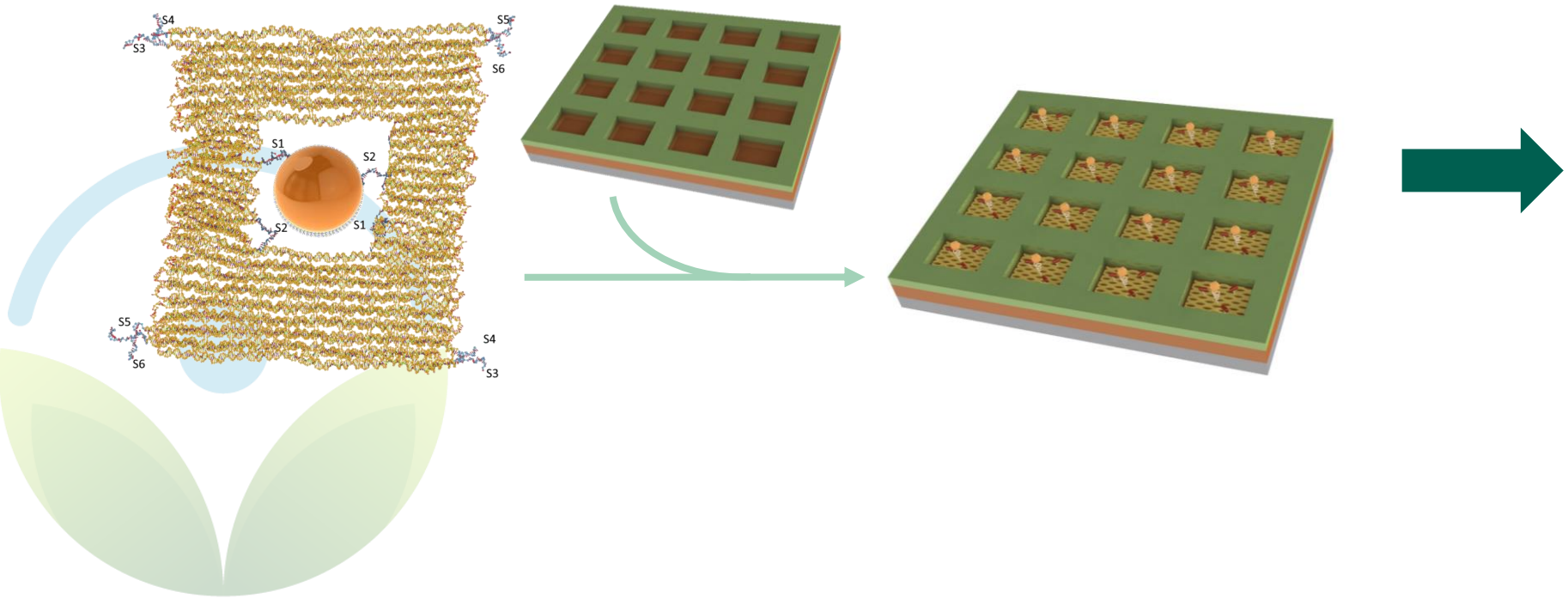
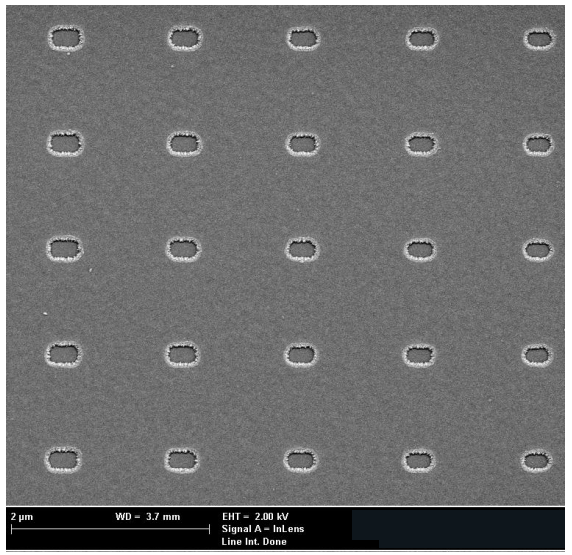
- Fabrication of Qdot LED to realize the ***Single Photon Source***
  - Wafer level technology for micro- and nanosystems
  - Deposition of functional layer to electrically contact the Qdot(s)
  - Preparing nanostructures to locally immobilize the DNA Origami
  - Deposition of DNA origami hybrids on nanostructured surfaces
  - Encapsule the DNA-Qdot-hybrid

    → **(single) Qdot LED**

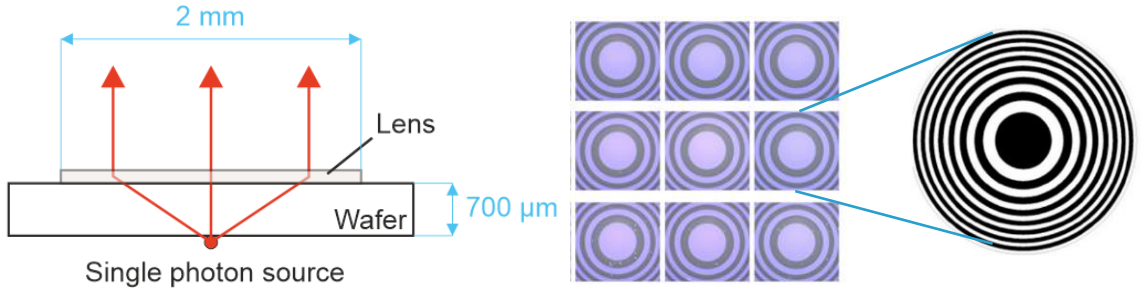


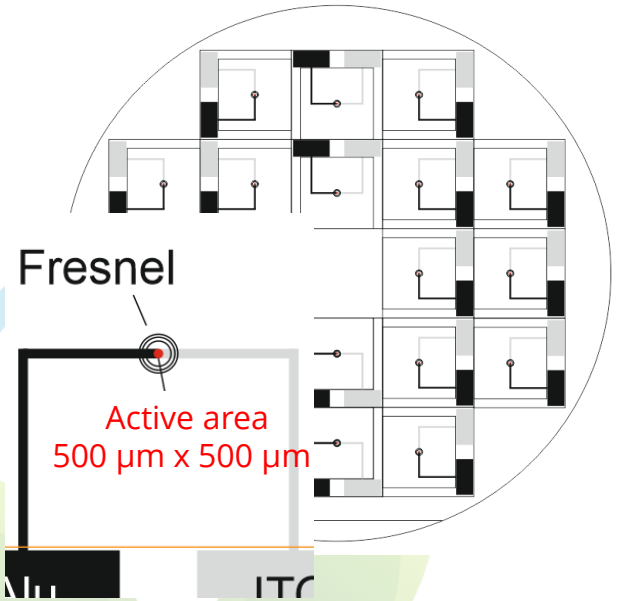


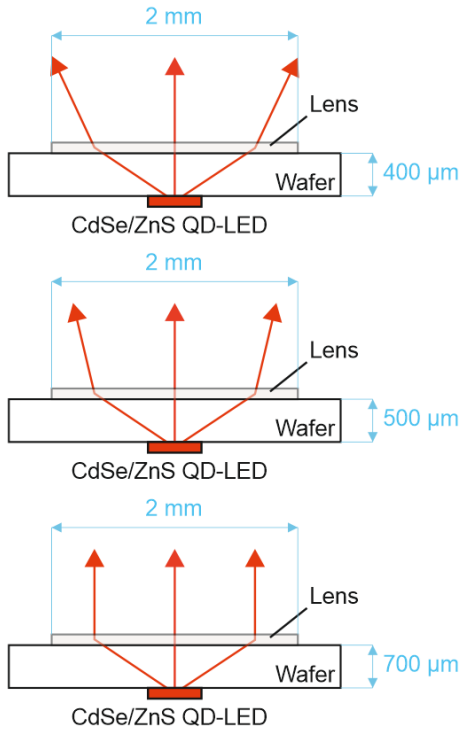


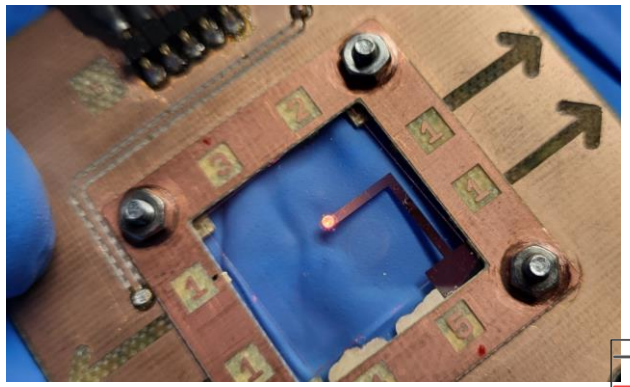
GREENER – Single Photon Source and focusing unit

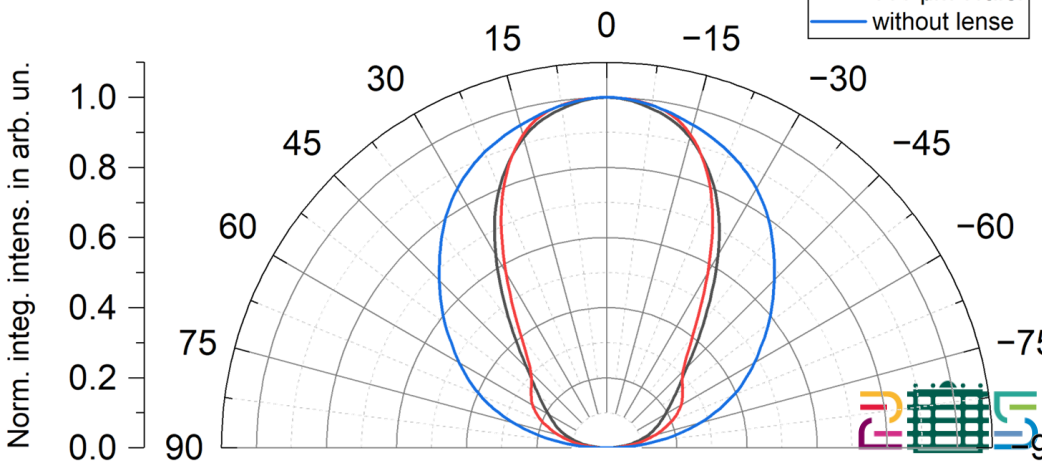
- Preparation of lenses on a transparent wafers
- Rear side preparation (**Single) Photon Source**
  - CdSe/ZnS QD-LED
- Measurement of the radiation pattern
  - Without lense: Lambertian radiator
  - With lense: narrow radiation





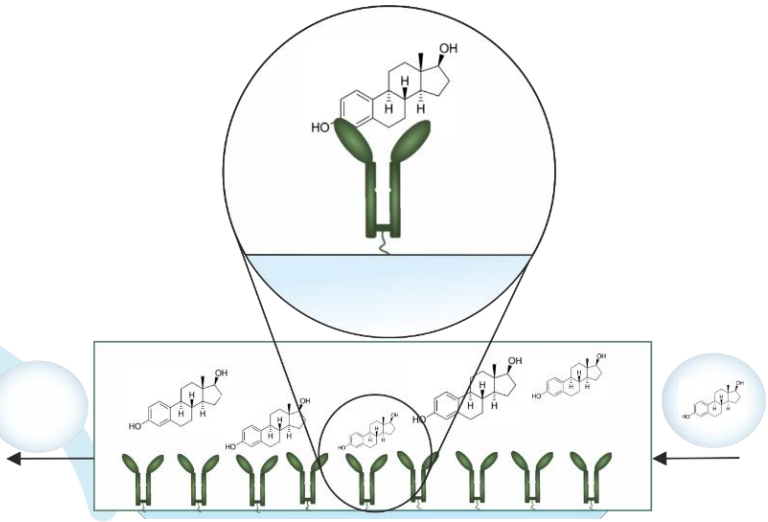




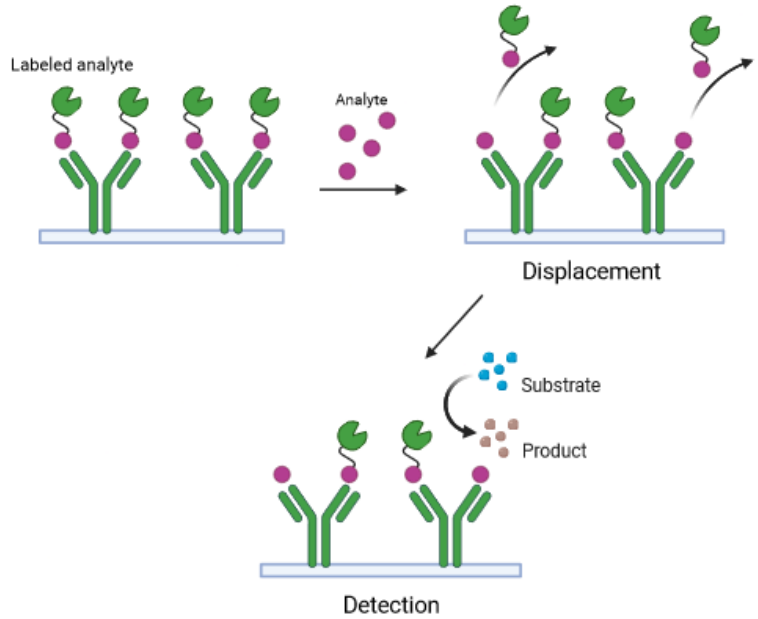


Objectives

- Design of production of transparent fluid cell suitable for detection of analytes
- Development and optimization of methodology for preconcentration of analytes in vicinity to the optical detector
- Design of the analytical detection procedure



- Selective pre-concentration of analyte molecules for **label-free** detection



- Labeling analyte molecules with AuNP or enzymes

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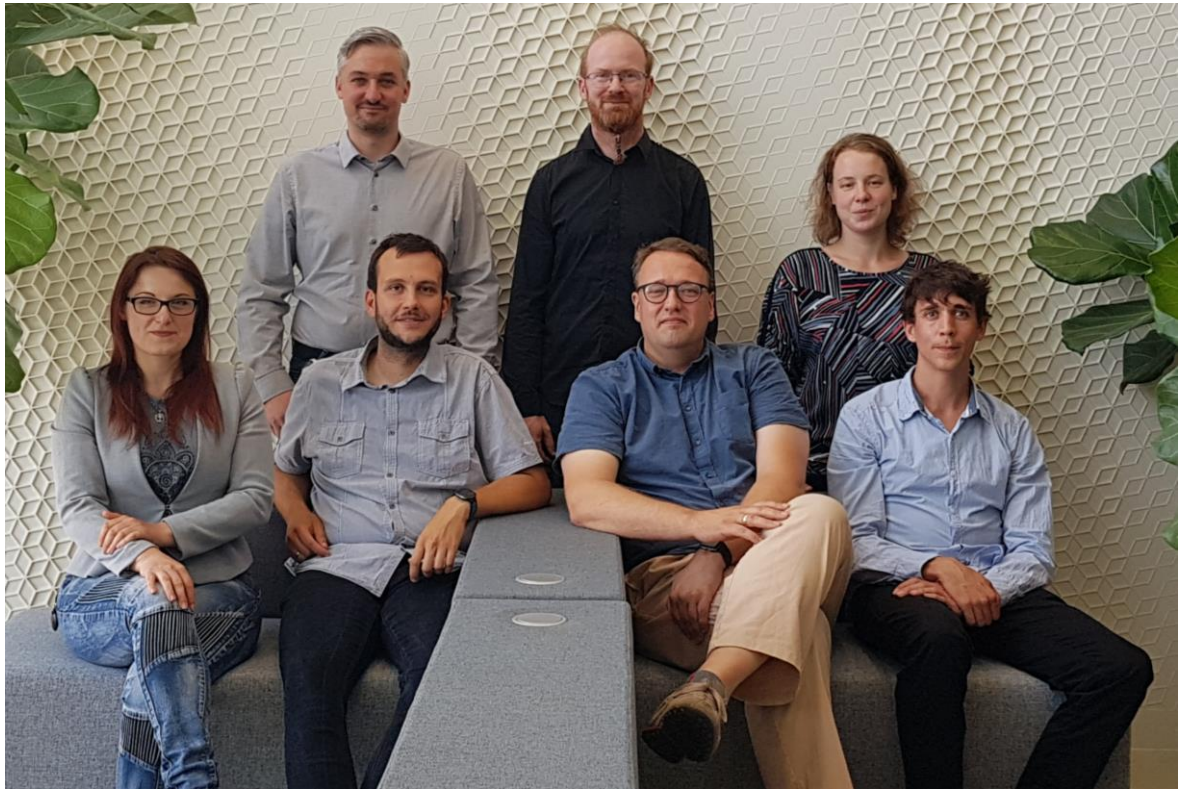

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