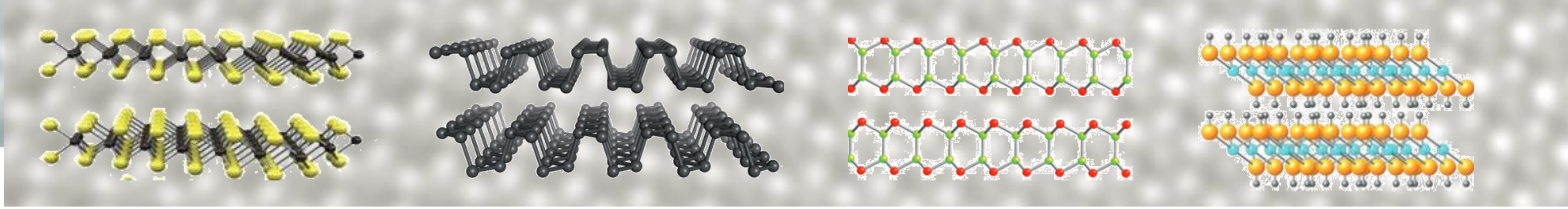
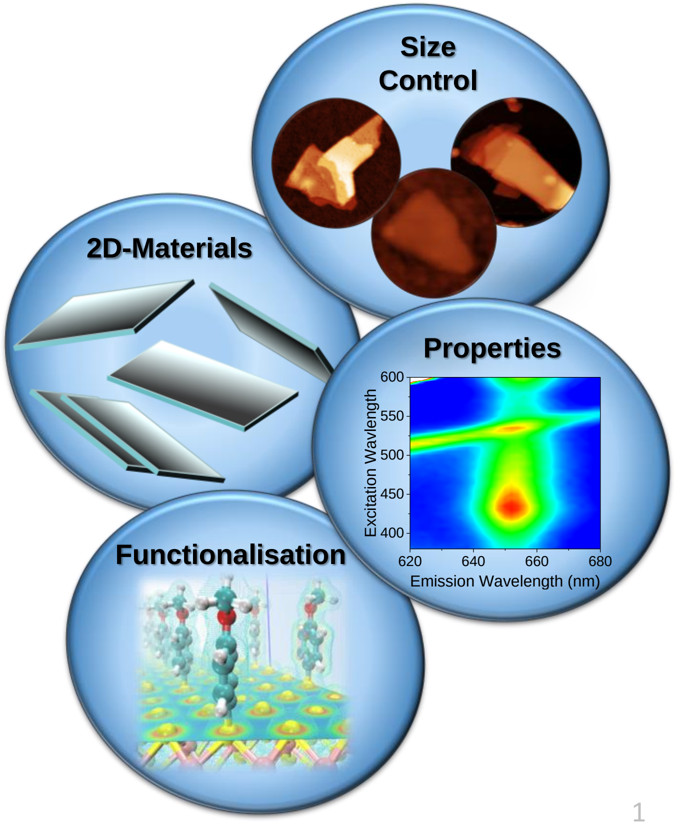


Nachwuchsgruppe Dr. Claudia Backes

In Lösung exfoliierte anorganische Schichtmaterialien (z.B. MoS_2, GaS, schw. P) als Bausteine für funktionale Architekturen

Themengebiete:

- **Prozessoptmierung der Exfoliierung**
- **Größenselektion (Zentrifugation…)**
- **Spektroskopische Eigenschaften**
  → Quantitative Größenbestimmung!
- **Funktionalisierung, chemische Dotierung**
- **Hierarchische Strukturen:**
  "mix and match"



Acknowledgement

Emmy Noether-Programm
Deutsche Forschungsgemeinschaft DFG

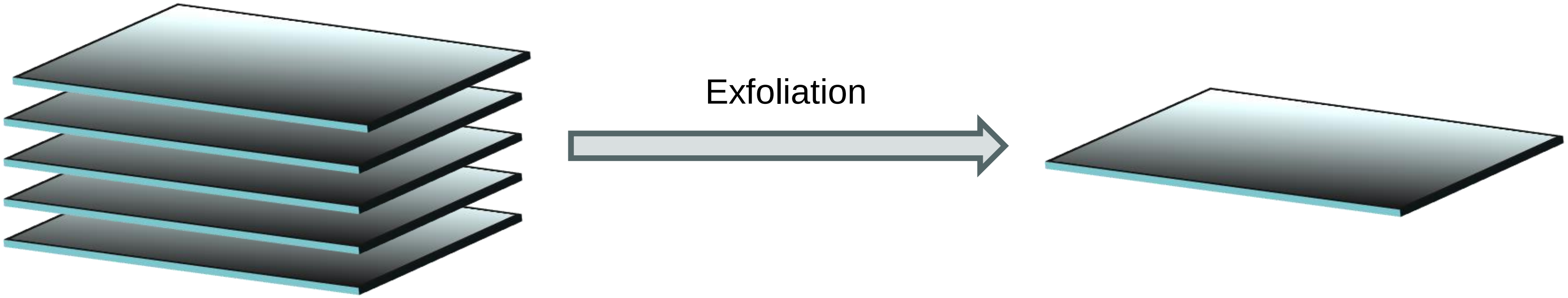
SFB 1249

VolkswagenStiftung

Lehrstuhl Angenwandte Phys. Chemie (Zaumseil)

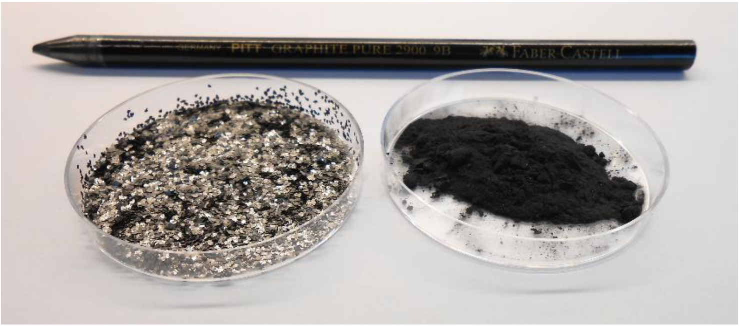
NMOE
NANOMATERIALS FOR OPTOELECTRONICS

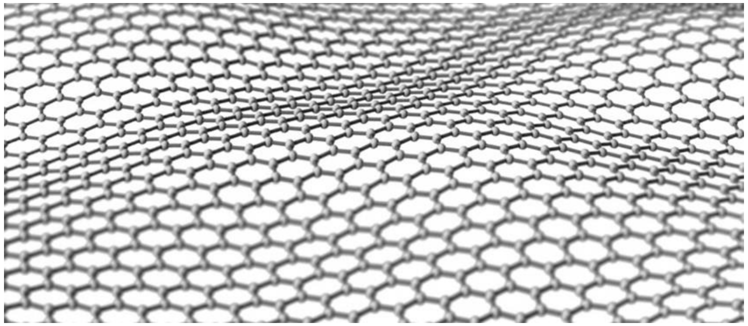
2D-materials



Graphite

Graphene





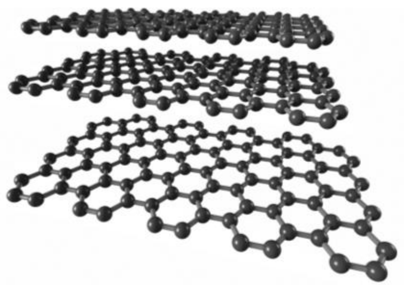
→ **Exciting physics and spectroscopy due to quantum confinement in 2D**

→ **Huge surface area: Old materials with new chemistry!**

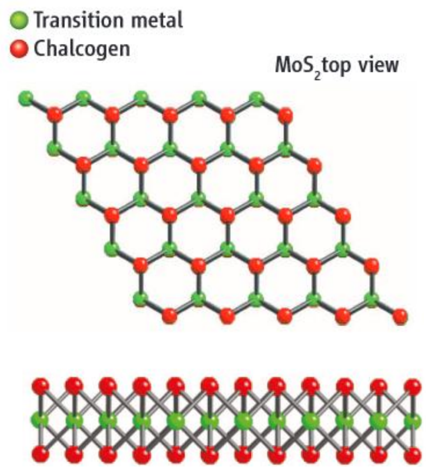
→ **Application potential in diverse areas (electronics, catalysis, energy)**

Spectroscopic metrics library

Graphite/Graphene

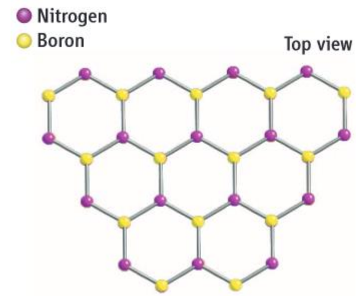


Transition metal dichalcogenides

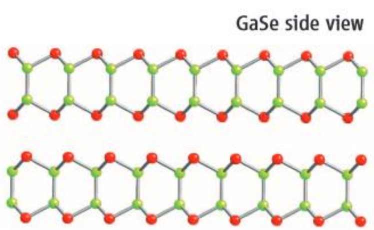


Single element; e.g. P, Sb

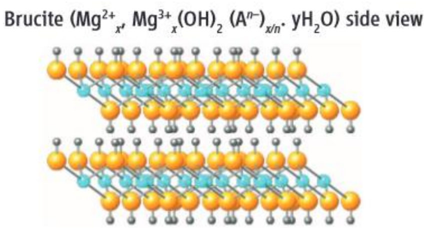
Hexagonal boron nitride



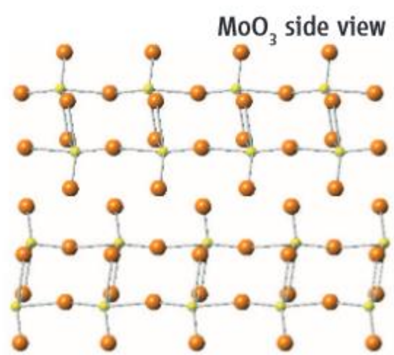
III-VI semiconductors



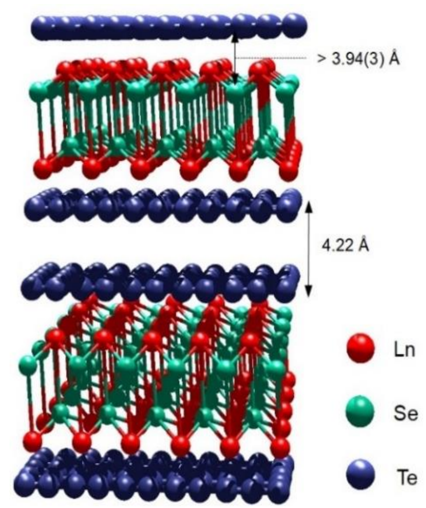
Layered hydroxides



Transition metal oxides

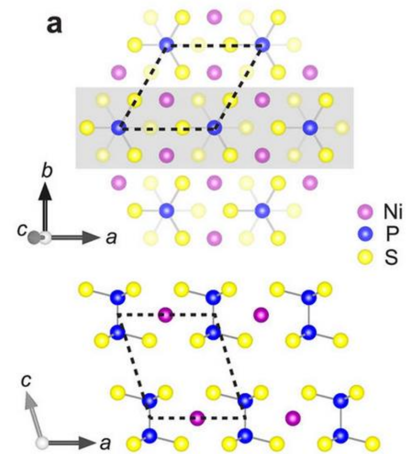


Rare earth polychalcogenides



Thomas Doert, TU Dresden

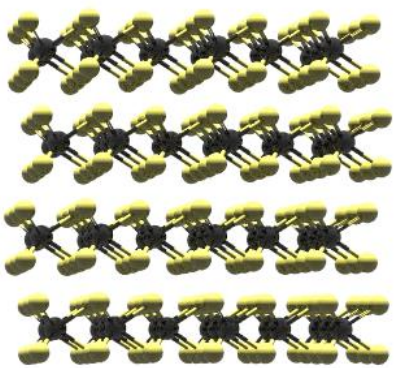
Transition metal phosphorus trisulfides

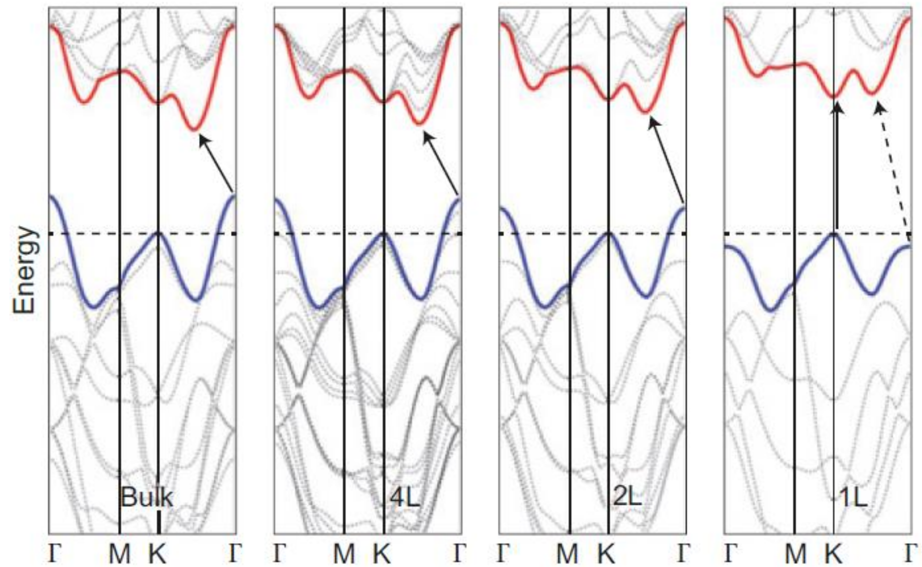


Wolfgang Bensch, Uni Kiel

2D-Transition metal dichalcogenides

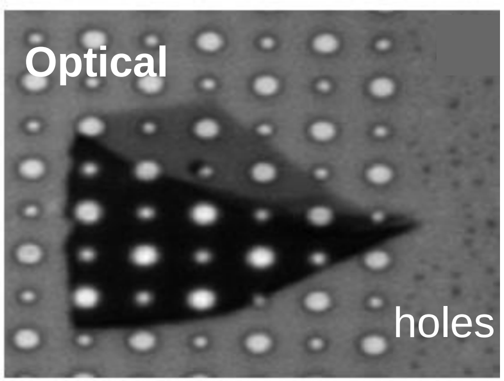
Quantum confinement in 2D materials

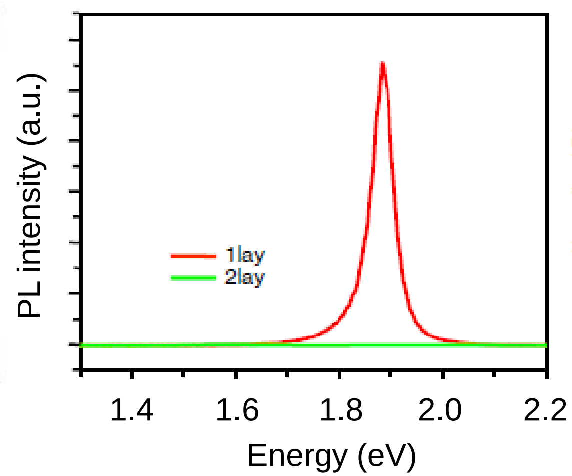




Direct gap Semiconductor

- → High absorption
- → Higher PL yield
- → Large exciton binding energy

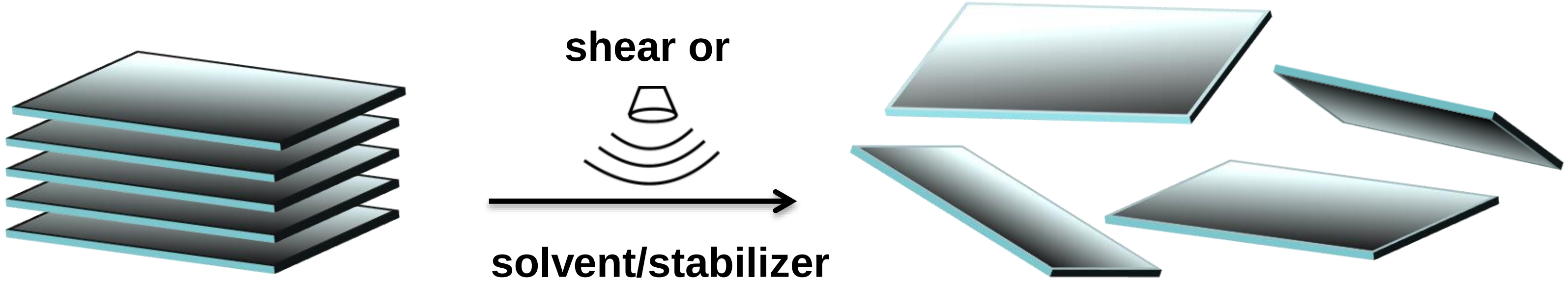


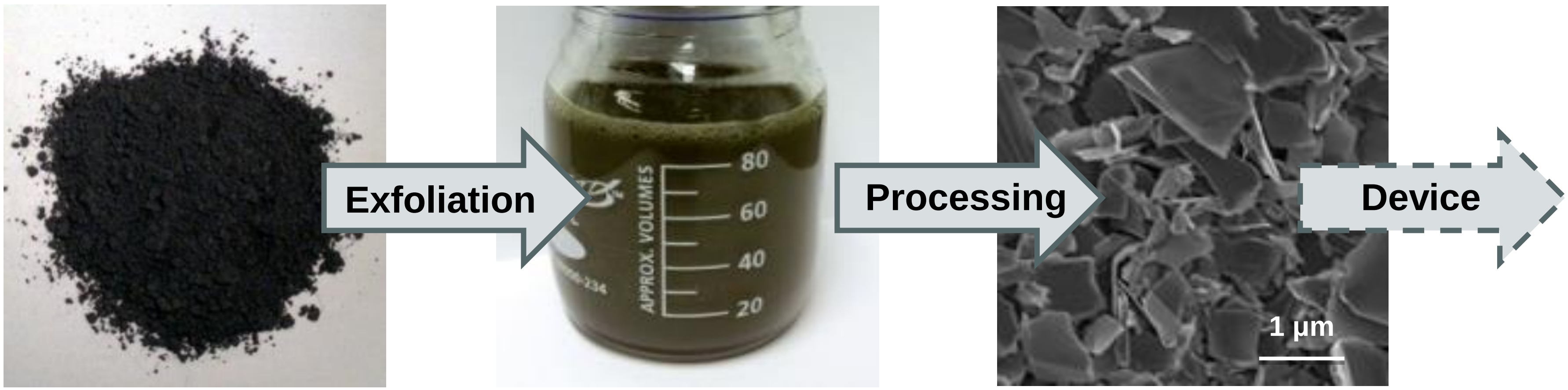


Splendiani *et al., Nano Lett.* **2010,** *10*, 1271; Mak *et al., Phys. Rev. Lett.* **2010,** *105*, 136805.

Liquid exfoliation

Liquid exfoliation: bulk quantities



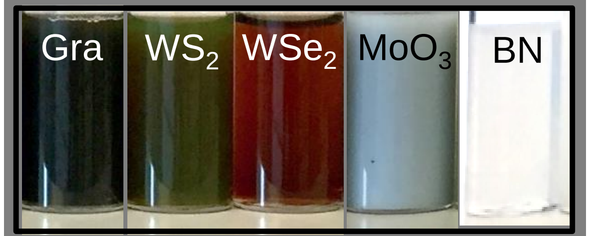


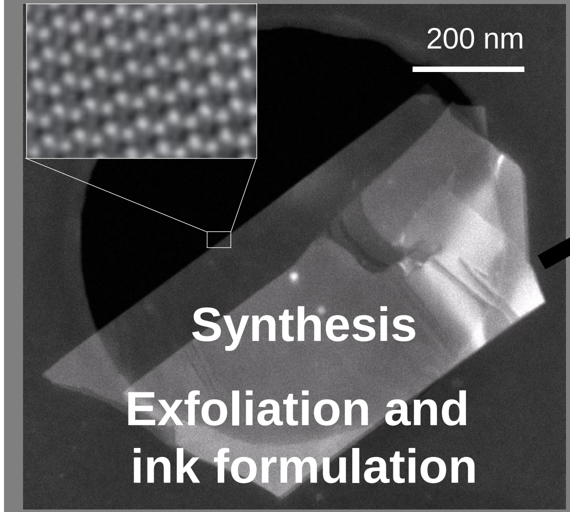
Coleman *et al.*,*Science* **2011**, 331, 568.
Bonaccorso *et al.*, *Adv. Mater.* **2016**, 28, 6136.

Backes *et al. JOVE* **2016**
Backes *et al. Chem. Mater.* **2016**

Process chain 2D-materials

Nanoscale





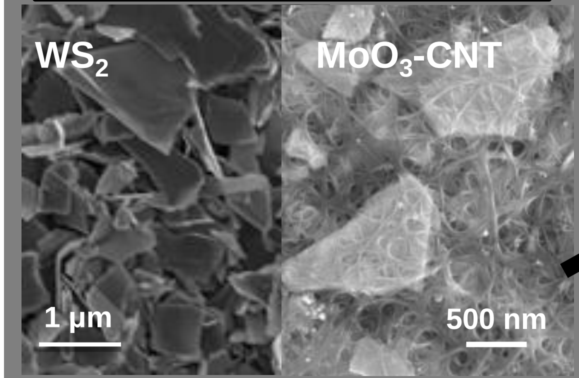
Synthesis

Exfoliation and ink formulation

Size control

Functionalisation

Mesoscale

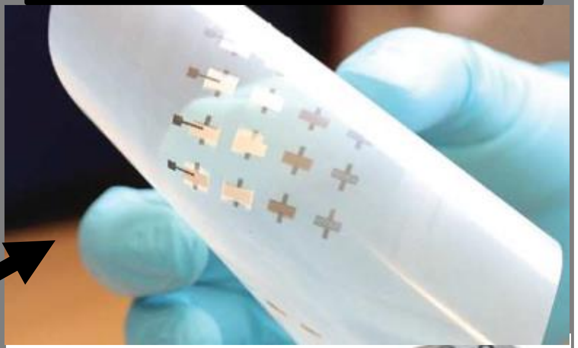


Deposition

Thin film formation

Hybrid & composite preparation

Macroscale



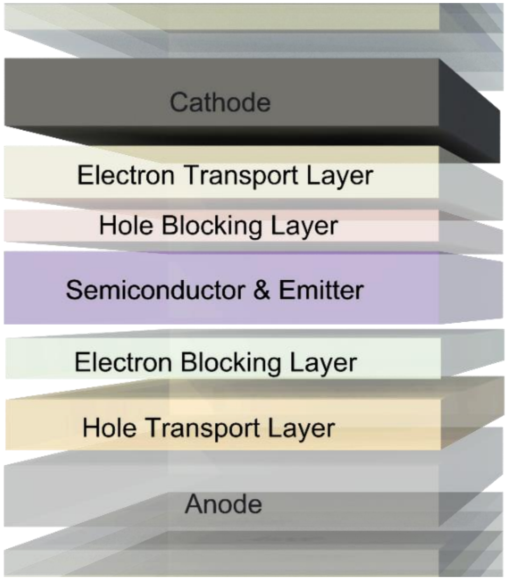
(Opto)electronics

Energy storage & conversion

Catalysis

Challenges example

Solutions to challenges by using chemistry ← Challenges (before device fabrication) ←



1. High quality samples (monolayers!)
2. Prevent restacking in films
3. Improve charge transport in layer
4. Tune emission properties (doping, quantum yield)
5. Understand and avoid degradation

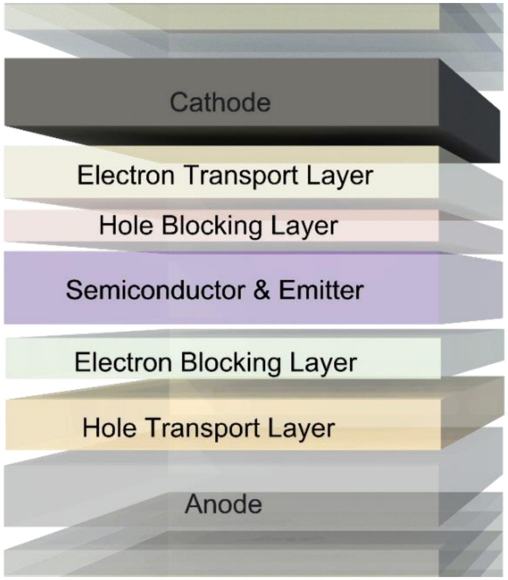
Challenges example

+

- Size control
- Size measurement

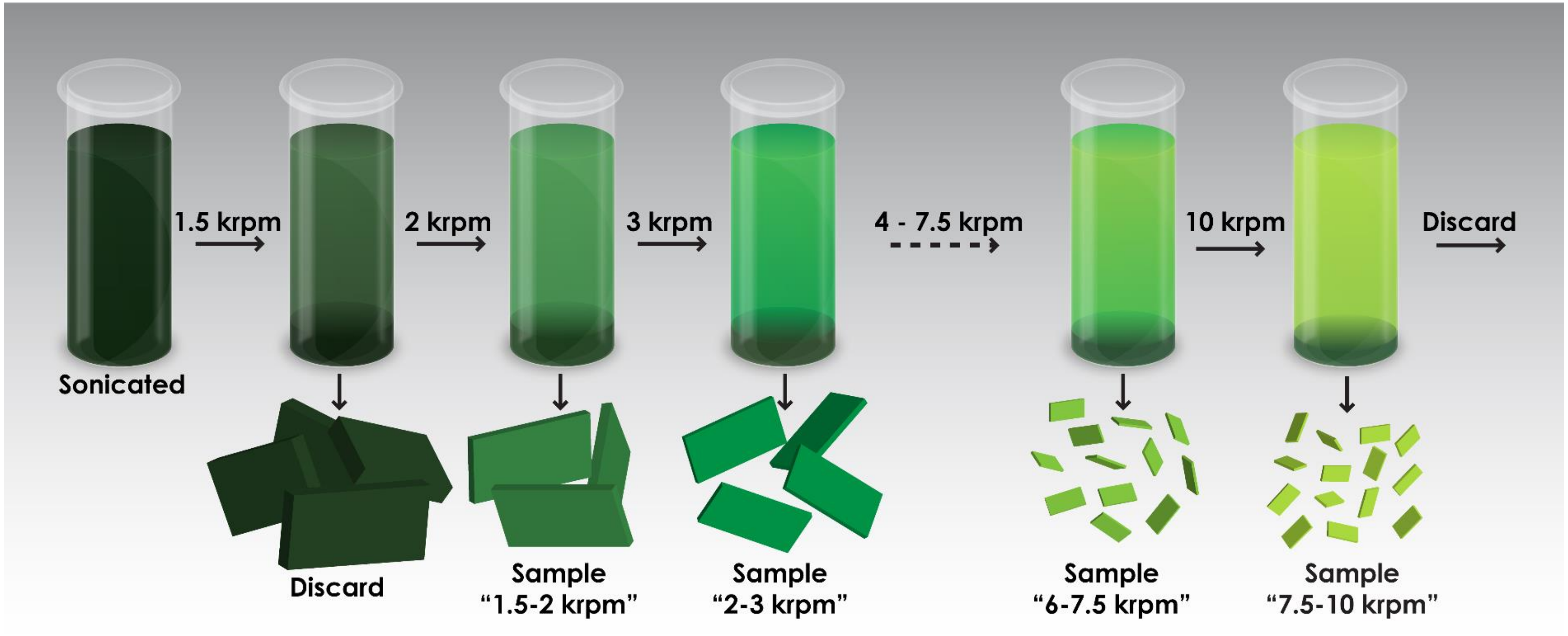
??

Pre-defined size, Monolayers



Size selection and measurement

Liquid cascade centrifugation



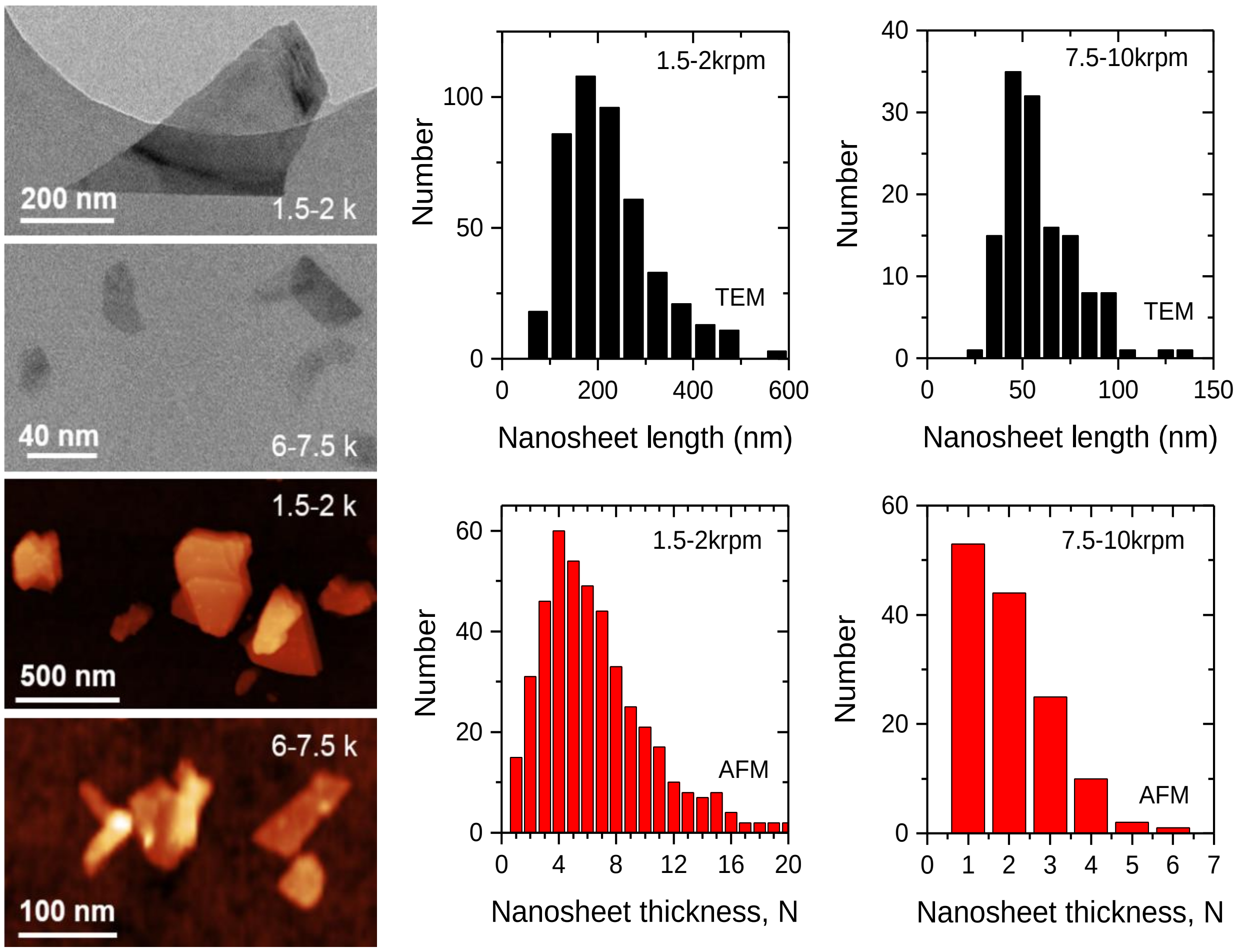
- **Advantages**
  - **Universally applicable (solvent, surfactant, any material)**
  - **Scalable and simple**
  - **No wastage of material**
  - **Depending on design, either size selection or monolayer enrichment**

Backes *et al.*, *ACS Nano* **2016**, 10, 1589

Size selection and measurement

Liquid cascade centrifugation: WS_2

- **Size and thickness measured by statistical microscopy**



Backes *et al.*, *ACS Nano* **2016**, 10, 1589

Spectroscopic metrics

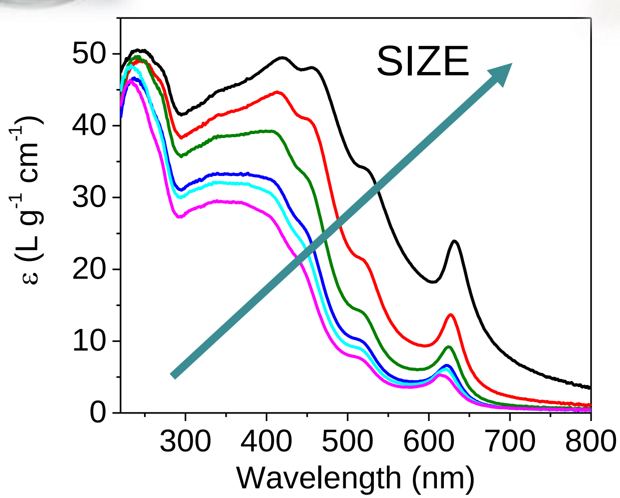
+

- Size control
- Size measurement

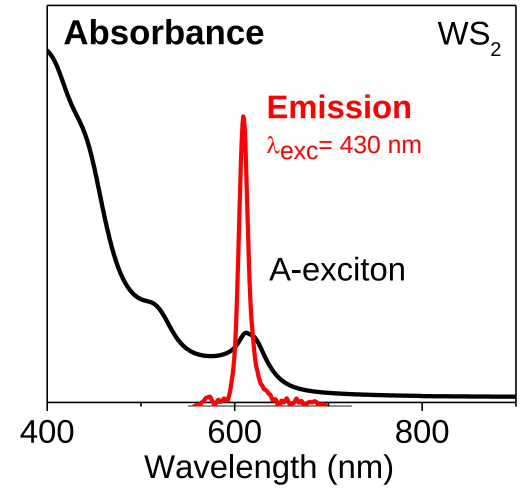
??

Metrics

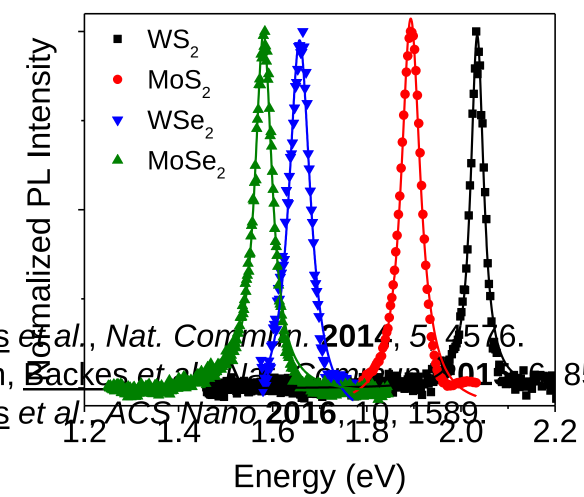
Pre-defined size, Monolayers



High monolayer content



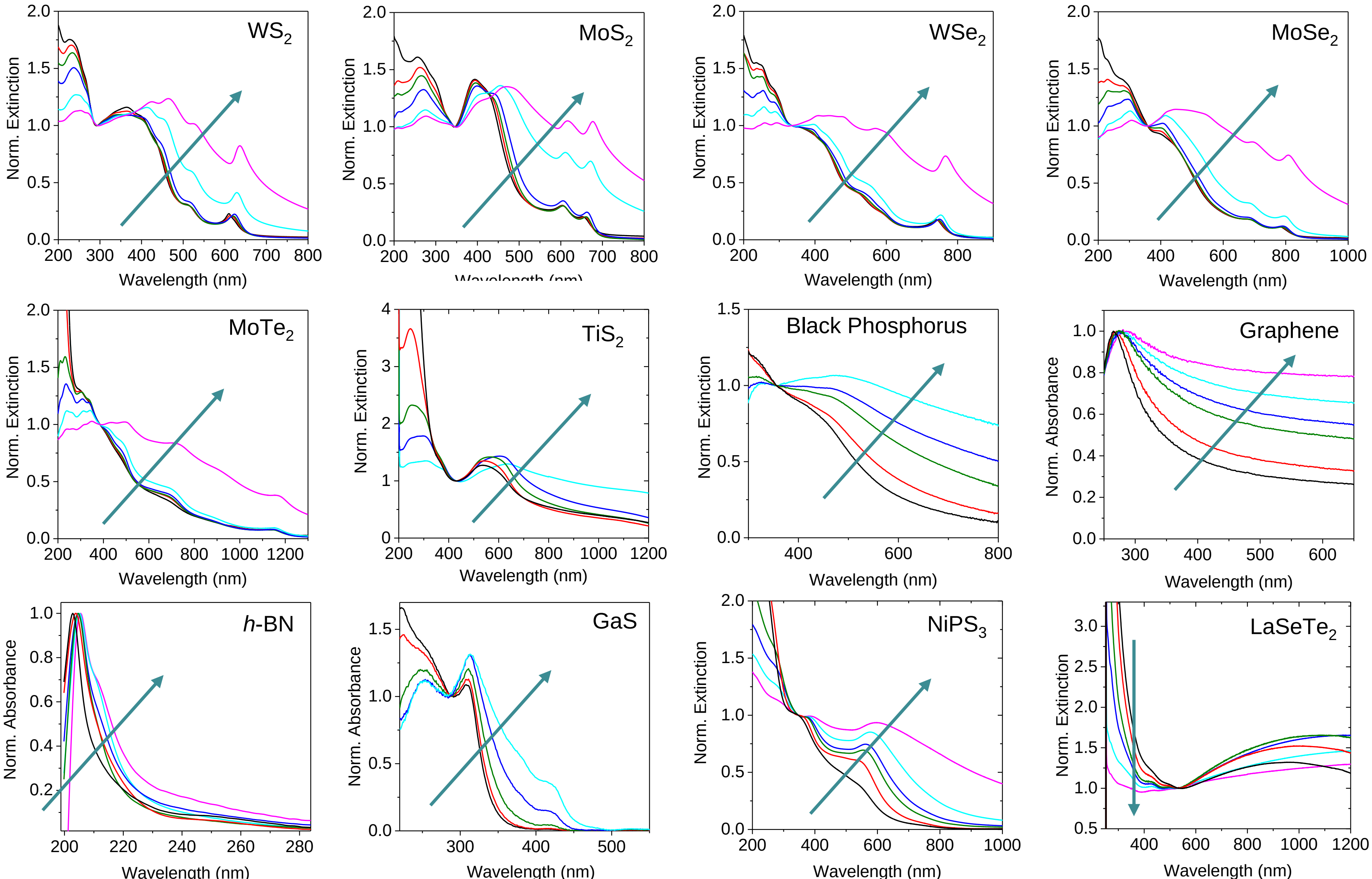
Applicable to various TMDs



Backes *et al.*, *Nat. Commun.* **2014**, *5*, 4576.
Hanlon, Backes *et al.*, *Nat. Commun.* **2015**, *6*, 8563.
Backes *et al.*, *ACS Nano* **2016**, *10*, 1589.

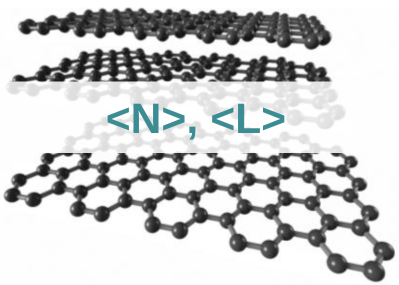
Spectroscopic metrics

Extinction/absorbance spectra various 2D-materials



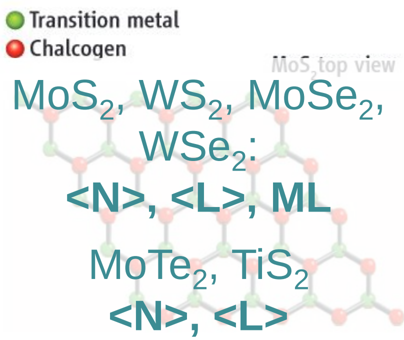
Spectroscopic metrics library

Graphite/Graphene



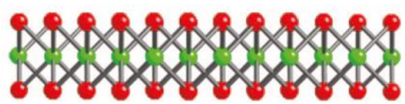
<N>, <L>

Transition metal dichalcogenides

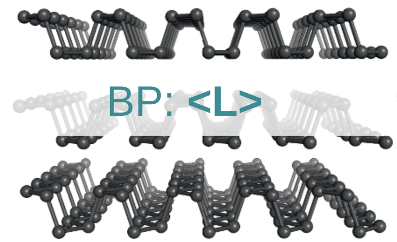


MoS_2, WS_2, $MoSe_2$, WSe_2:
<N>, <L>, ML

$MoTe_2$, TiS_2
<N>, <L>

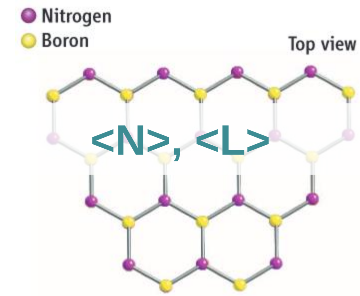


Single element; e.g. P, Sb



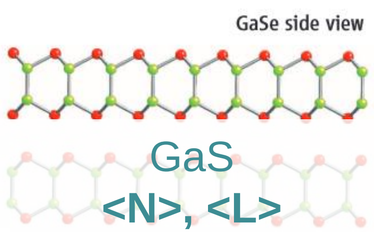
BP: **<L>**

Hexagonal boron nitride



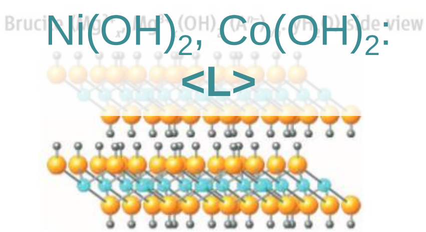
<N>, <L>

III-VI semiconductors



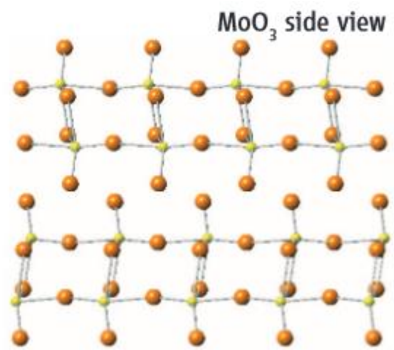
GaS
<N>, <L>

Layered hydroxides

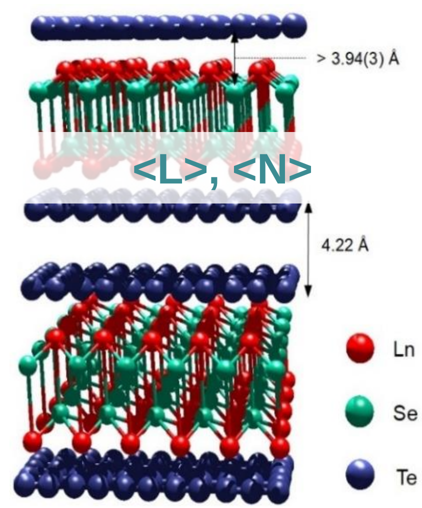


$Ni(OH)_2$, $Co(OH)_2$:
<L>

Transition metal oxides



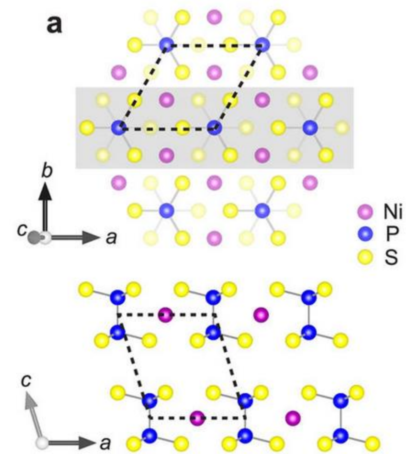
Rare earth polychalcogenides



<L>, <N>

Thomas Doert, TU Dresden

Transition metal phosphorus trisulfides



Wolfgang Bensch, Uni Kiel

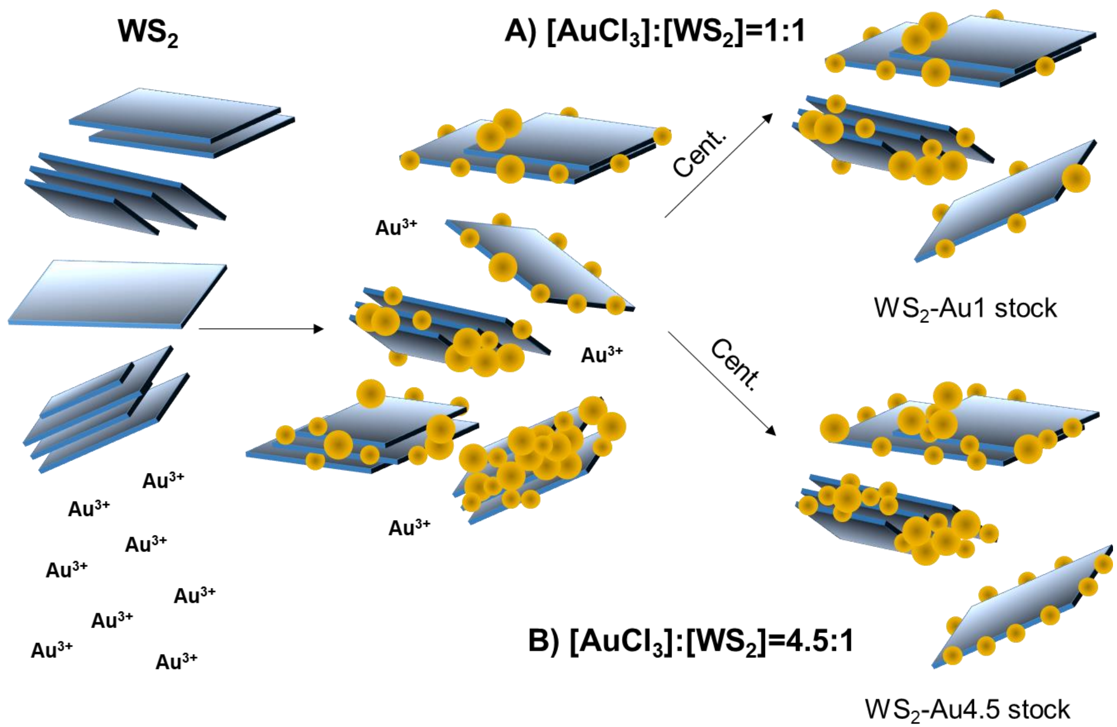
Functionalisation of TMDs

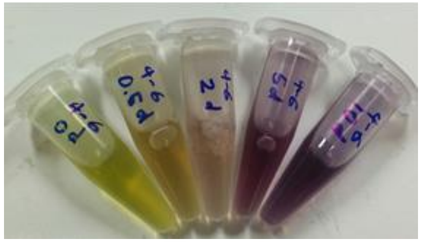
Edge decoration with Au nanoparticles

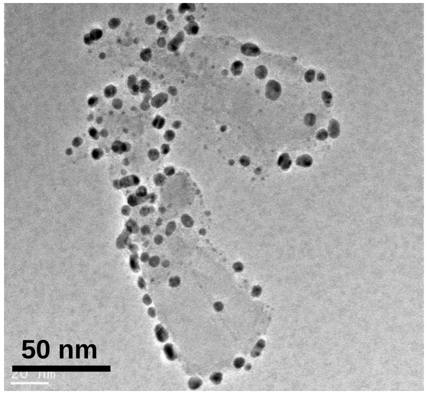
- Spontaneous reaction of WS_2 with $AuCl_3$

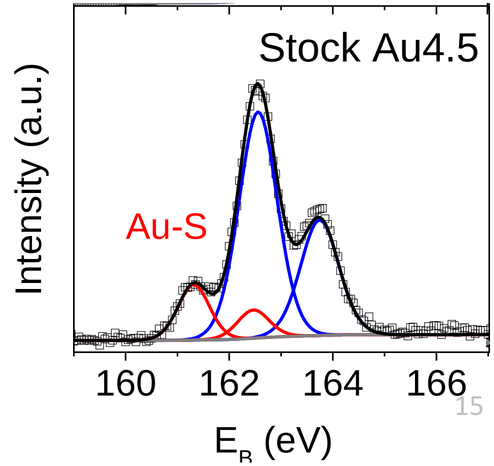
→ Formation of covalently bound Au nanoparticles predom. at edges

- Tuning of reaction conditions possible to change Au decoration density







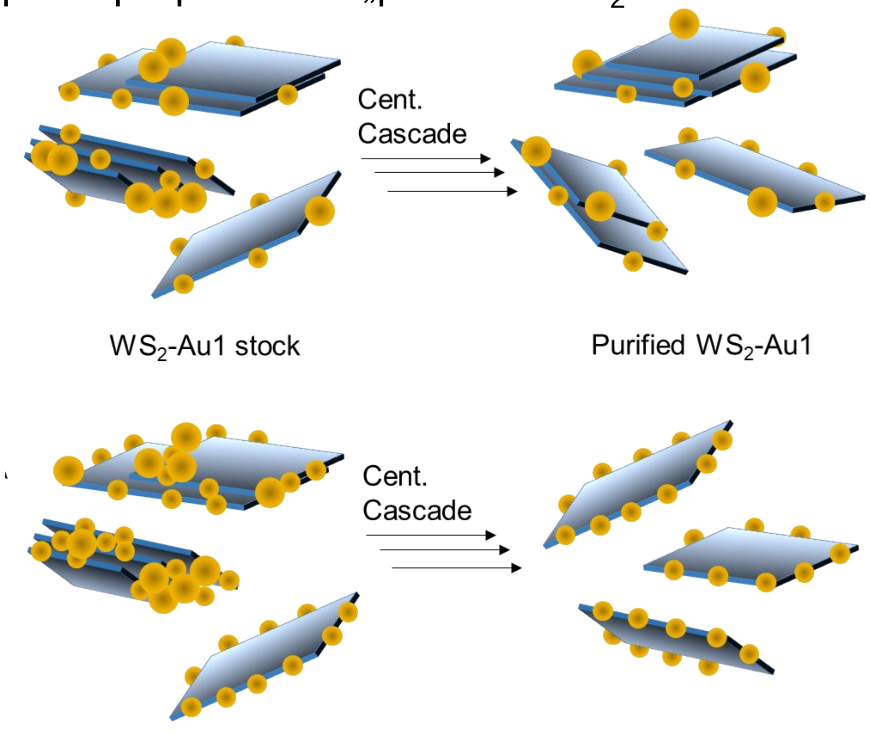


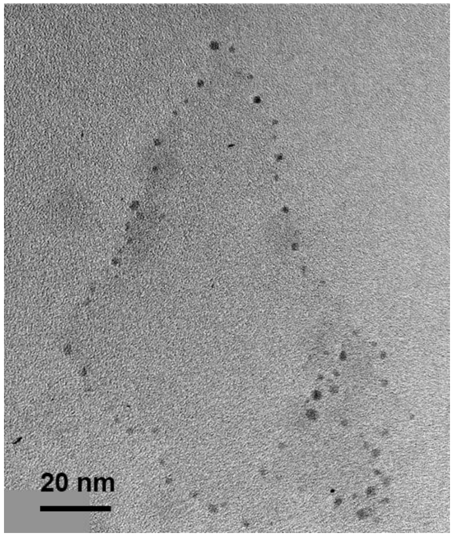
Dunklin, J. ….Backes, C., *Nature 2D Mater. App.* **2017**, accepted.

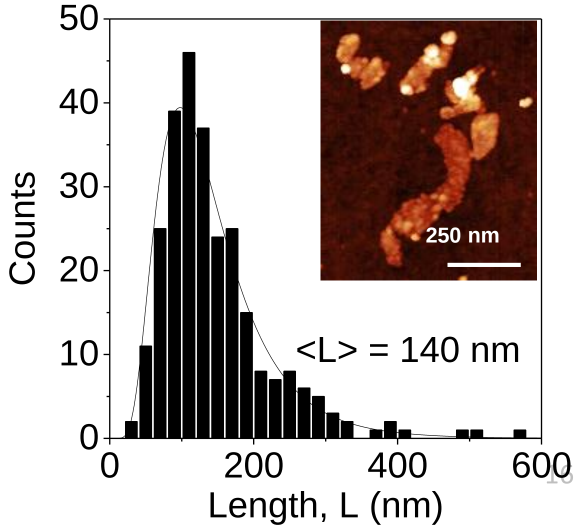
Functionalisation of TMDs

Edge decoration with Au nanoparticles

- Heavily Au decorated WS_2 removed by centrifugation
- Likeliness of NPs to merge higher on few-layer nanosheets
  → **monolayer enrichment** (tuneable lateral size)
- Optical properties of „pristine“ WS_2





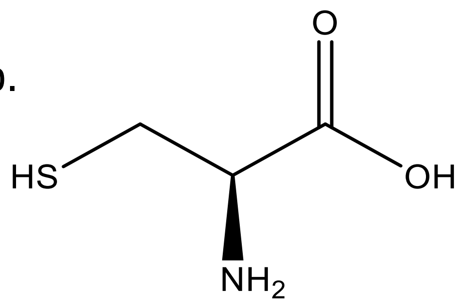


Dunklin, J. ….Backes, C., *Nature 2D Mater. App.* **2017**, accepted.

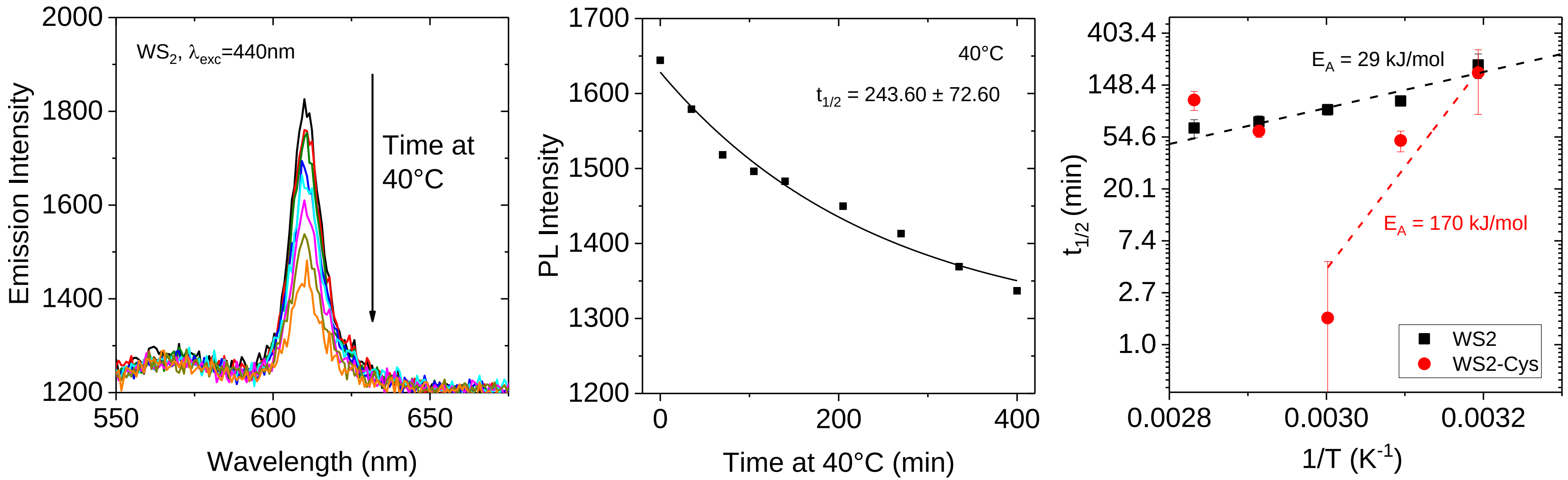
Functionalisation of TMDs

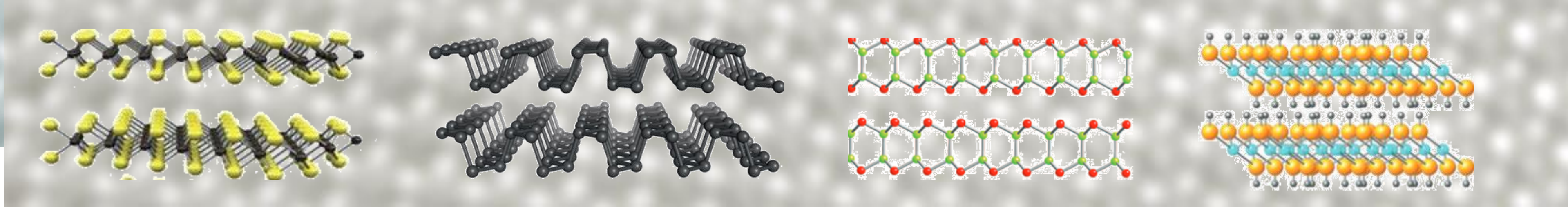
Defect passivation

- TMD monolayer degrade in ambient conditions at elevated temp.
- Can be followed by decay of photoluminescence
- Measurements at different temperatures yield activation energies in the range of 30 kJ/mol for WS_2



→ Defect passivation for example by cysteine can improve stability!



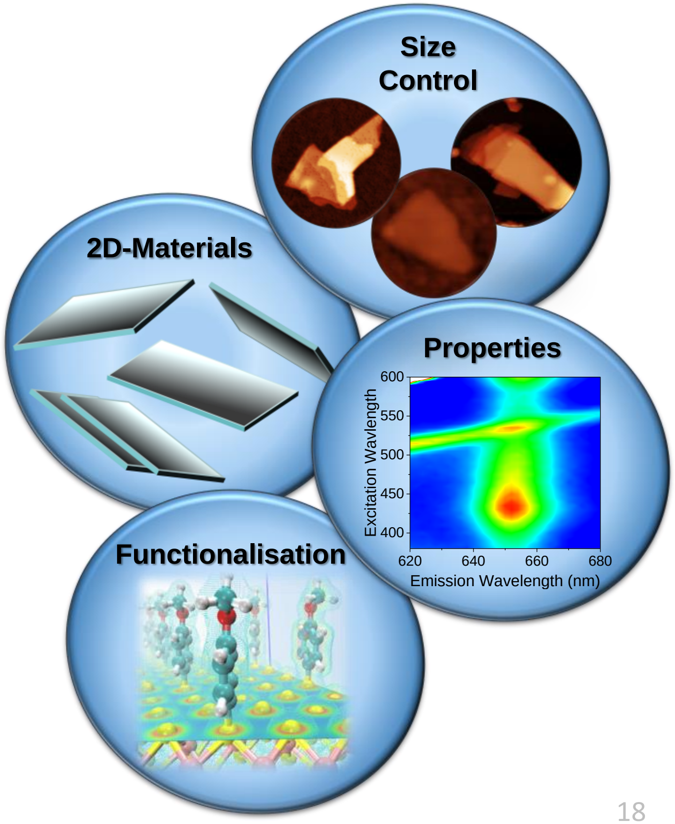


Nachwuchsgruppe Dr. Claudia Backes

In Lösung exfoliierte anorganische Schichtmaterialien (z.B. MoS_2, GaS, schw. P) als Bausteine für funktionale Architekturen

<u>Themengebiete</u>:

- **Prozessoptmierung der Exfoliierung**
- **Größenselektion (Zentrifugation…)**
- **Spektroskopische Eigenschaften**
  → Quantitative Größenbestimmung!
- **Funktionalisierung, chemische Dotierung**
- **Hierarchische Strukturen:**
  "mix and match"



Helping hands are always welcome!

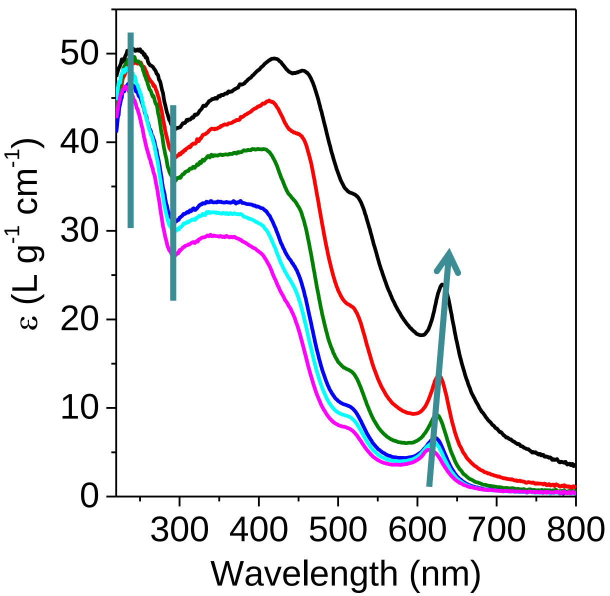
Thank you for your attention!

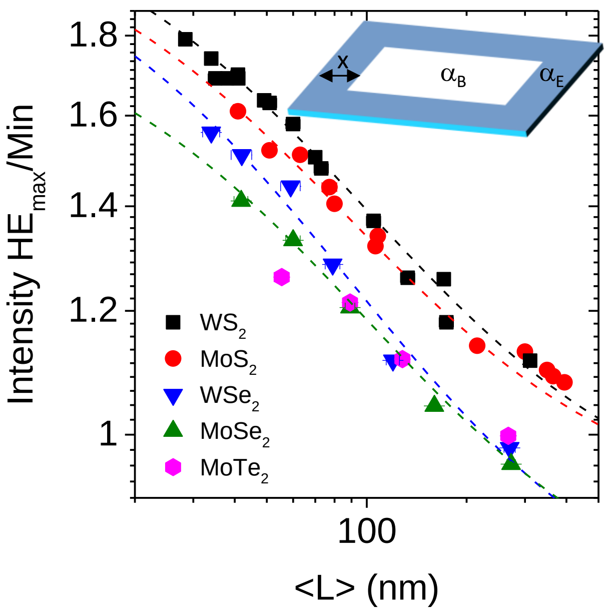
Spectroscopic metrics

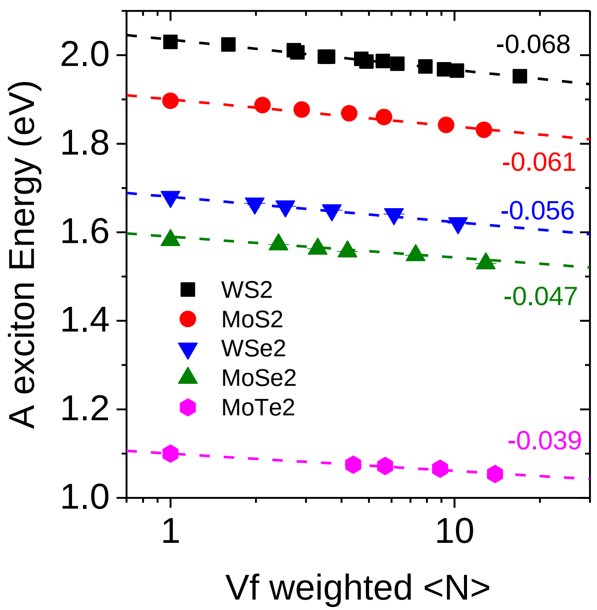
Metrics from extinction spectra

- **Changes in extinction peak intensity ratios due to edge effects → metrics for lateral size**

- **A-exciton shift due to confinement → thickness metric**







$$\frac{Ext_1}{Ext_2} = \frac{\alpha_{B,1} + 4x\alpha_{E,1}/L}{\alpha_{B,2} + 4x\alpha_{E,2}/L}$$

Backes *et al.*, *Nat. Commun.* **2014**, 5, 4576.

Backes *et al.*, *ACS Nano* **2016**, 10, 1589.