Friedrich-Schiller-Universität Jena

Heterostructures of 2D materials and organic semiconductor nanolayers (H2O)

Consortium:

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- **Prof. Sergey Kubatkin, Dr. Saroj Prasad Dash, Dr. Samuel Lara Avila**
  Chalmers University of Technology, Gothenburg, Sweden
- **Dr. Michel de Jong**
  University of Twente, Enschede, Netherlands

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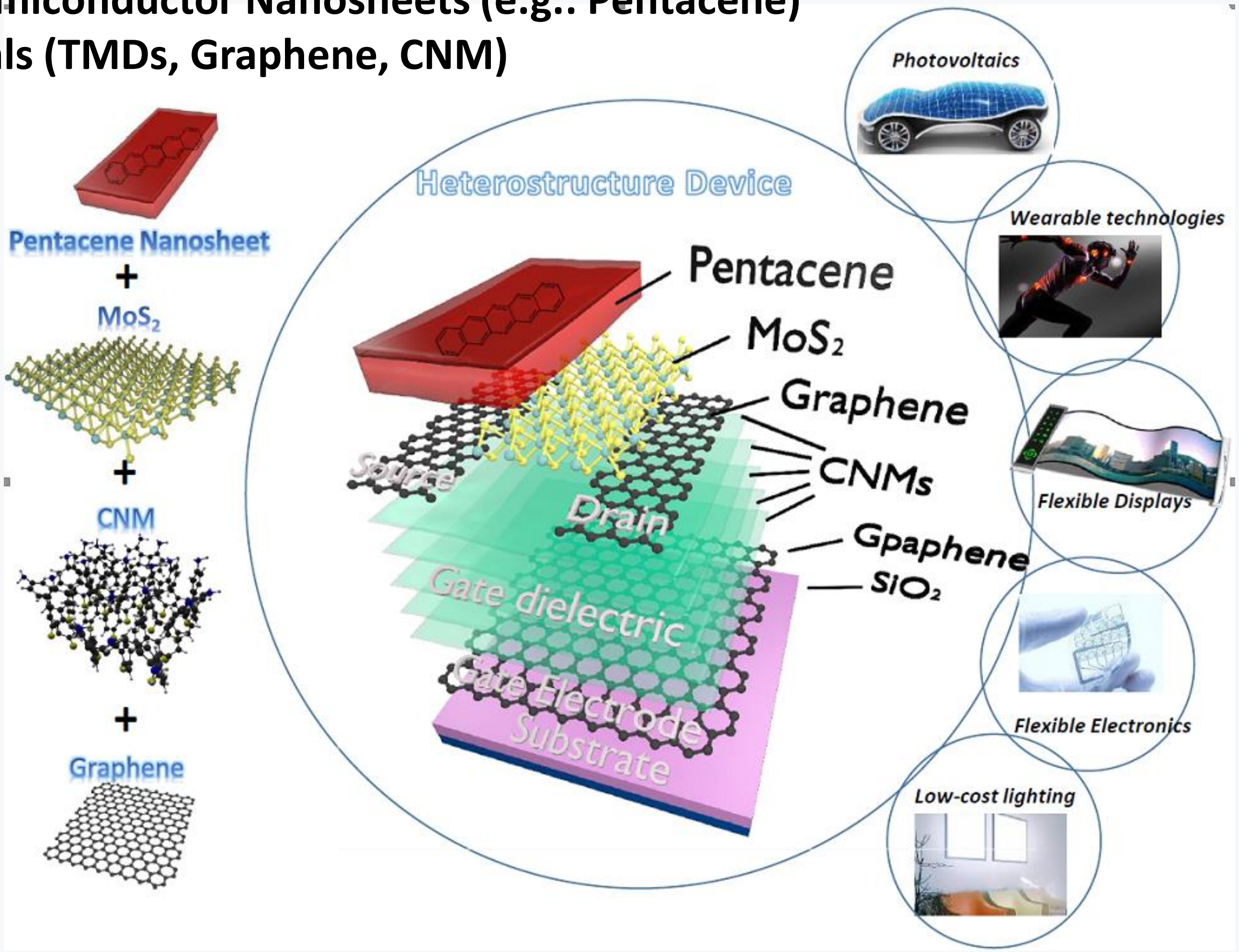
seit 1558

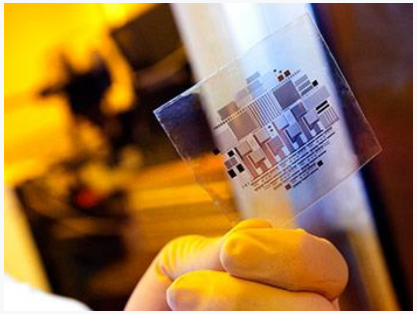
Introduction

van der Waals Heterostructures for Device Applications

- **Organic Semiconductor Nanosheets (e.g.: Pentacene)**
- **2D materials (TMDs, Graphene, CNM)**

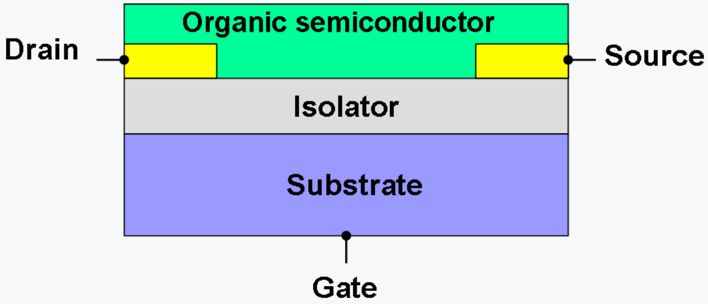


Organic Semiconductors (OSC)



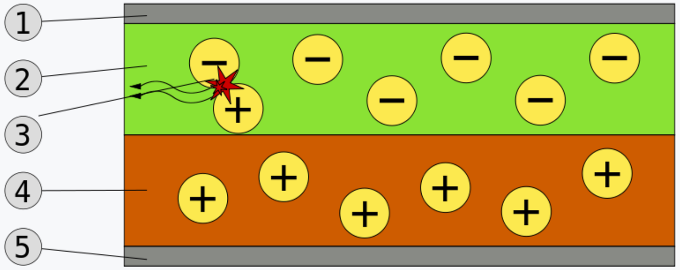
- Low cost technology
- Compatibility with flexible plastic substrates
- Low temperature processing (60-120°C)
- Adjustable electronic characteristics by chemical tuning
- Compatible for solution monitoring and innovative applications such as biodegradable electronics

Organic Field Effect Transistor (OFET)



- Charge carrier mobility in organic devices ranging from 10^{-5} to 1 cm^2/Vs

Organic Light Emitting Diode (OLED)



Schematic of a bilayer OLED: 1. Cathode (−), 2. Emissive Layer, 3. Emission of radiation, 4. Conductive Layer, 5. Anode (+)

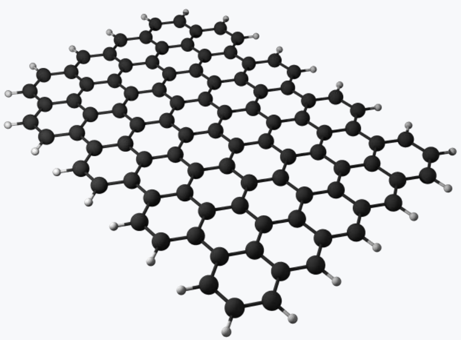
Organic Semiconductor Technology and Market

- Commercialized technology, several products in market
- Companies Involved: BASF, Bayer, Philips, Merck, Novaled, Samsung, Sony, LG etc.
- Products: High Resolution Displays, Medical Devices, OLED Lighting Panels, Organic Solar Cells
- Market size of 45 Billion USD (2017)

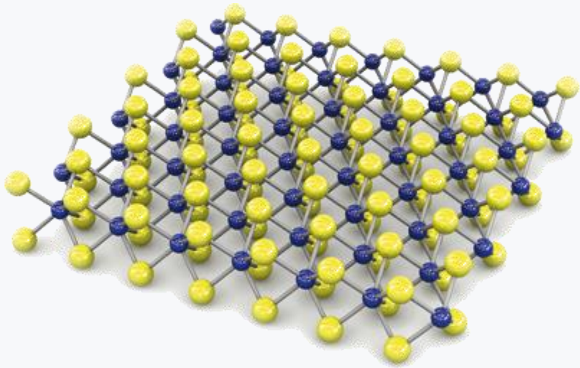
2D materials

- Atomically thin single layer materials
- Available in metallic (graphene), semiconducting (MoS_2, WS_2, WSe_2) and insulating (hBN, CNM) forms
- Flexible, transparent and light weight
- High charge carrier mobility and good optoelectronic characteristics
- Compatibility with plastic substrates
- Promising materials for emerging electronic, optoelectronic, energy and sensing device applications

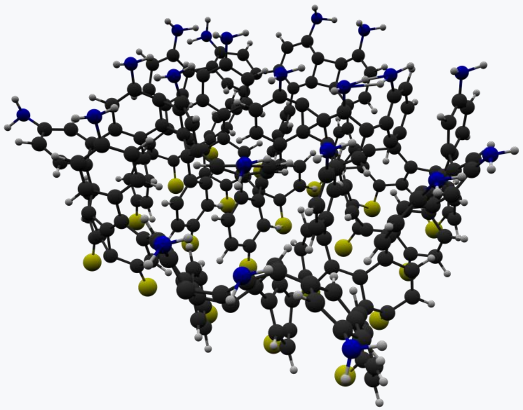
Graphene



TMD (MoS_2, WSe_2, WS_2)



Carbon Nanomembranes (CNM)



Carbon Nanomembranes, A. Turchanin and A. Gölzhäuser, Advanced Materials, 28, 6075, 2017

Lateral Heterostructures of Two-dimensional Materials by Electron-beam Induced Stitching, A. Winter, A. George, A. Turchanin et al., Carbon, 128, 106, 2018

Challenges in building 2D material-OSC vdW heterostructures

- **Organic Semiconductor structural quality depends on the growth substrate and growth conditions.**

- **Direct deposition of OSC layers on 2D materials may result low structural quality (low crystallinity)**

- **Lower interfacial quality resulting in poor performance of the heterostructure devices**

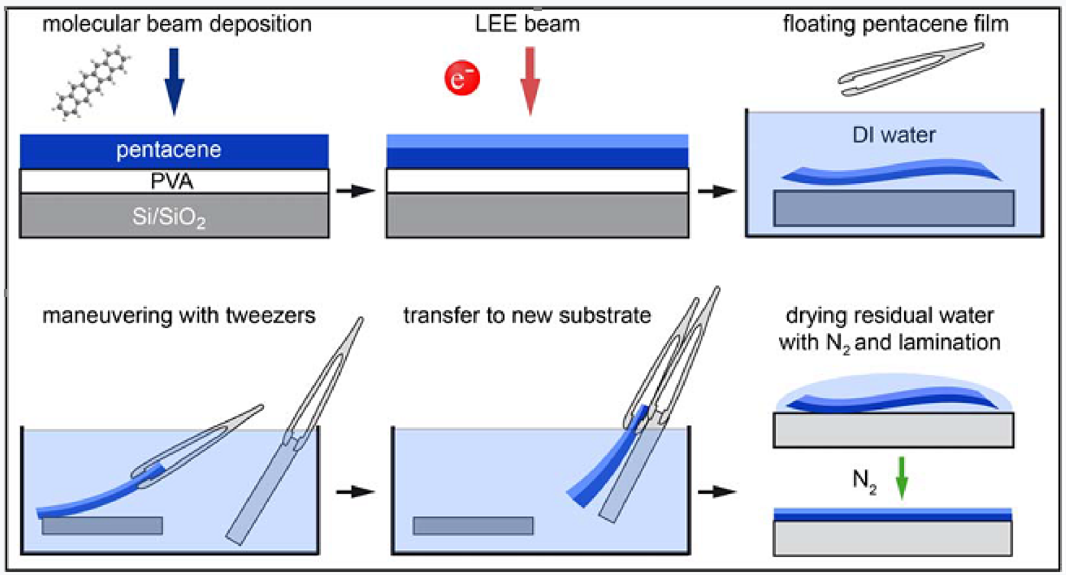
- **A viable solution : Transferrable organic semiconductor films to any arbitrary substrate**

vdW heterostructures of OSC and 2D materials

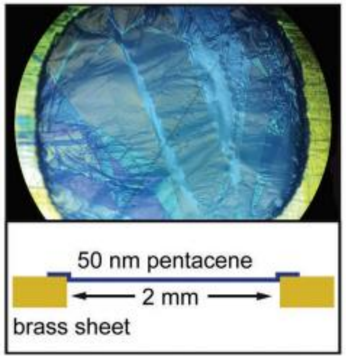
Transferable OSC nanosheets

- Pentacene films (20-50 nm) can be grown with high crystallinity on polyvinyl alcohol (PVA) thin films.
- After the growth on PVA, the top molecular layers (~ 5 nm) are cross linked by e-beam irradiation.
- The crosslinked top layer stabilizes the film and become transferrable to any arbitrary substrate without loosing its structural/electronic quality.
- The technique can be extended to other OSC materials

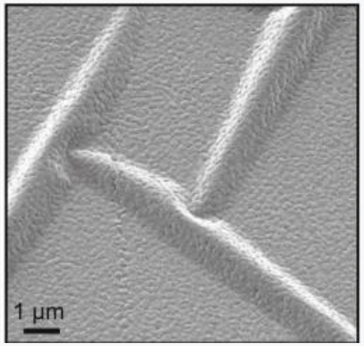
Fabrication process of transferrable OSC nanosheets



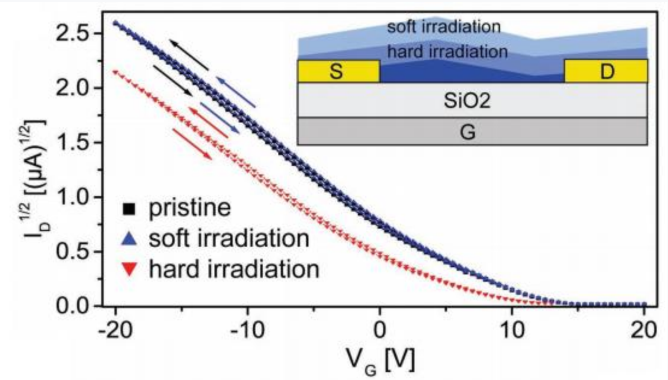
Optical microscopy



HIM image



Transistor characteristics



Transferable Organic Semiconductor Nanosheets for Application in Electronic Devices, S. J. Noever, A. Turchanin, B. Nickel et al., Advanced Materials, 23, 1606283, 2017

Consortium Partners and Expertise

Friedrich Schiller University Jena, Germany	Ludwig Maximilian University Munich, Germany	Chalmers University of Technology, Sweden	University of Twente, Enschede, Netherlands
Expertise: 2D materials synthesis, characterization, nanofabrication, nano (opto)electronic devices	**Expertise:** Organic semiconductors, photocurrent spectroscopy, organic (opto)electronic devices	**Expertise:** Advanced nanofabrication for complex device architectures, advanced transport measurements, device physics	**Expertise:** Synchrotron based spectroscopic studies of nanolayers and heterostructures
Facilities: CVD growth, E-beam processing, Optical microscopy, Raman Spectroscopy, XPS, HRTEM, SEM, cryogenic vacuum probe station, sensor testing, cleanroom nanofabrication	**Facilities:** Organic semiconductor processing, laser writing lithography, probe station, photocurrent spectroscopy	**Facilities:** Cleanroom nanofabrication, cryogenic vacuum probe station	**Facilities:** ARPES, ARUPS, XPS

H2O Kick-off meeting in Jena (1st March 2018)

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