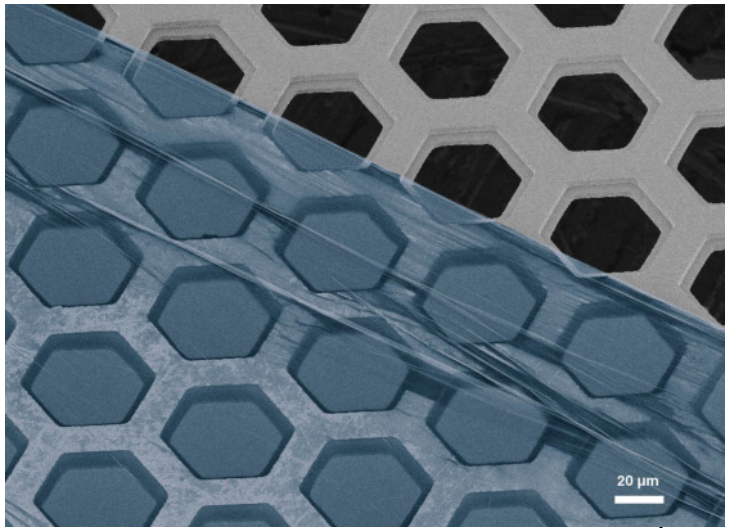
CNM TECHNOLOGIES

Carbon Nanomembranes –

A New Class of Material for Disruptive Applications



June 2018

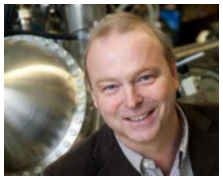
CNM Technologies GmbH

Company Details

Details: Founded in 2011; Start of operational activities in 2012
CNM Technologies holds all patents relevant to carbon nanomembranes.

Activities: Production, sales, and development of new applications of CNMs.

Founding Partners and Shareholders:



- **Dr. Albert Schnieders:** managing director, founder, physicist, former general manager of Tascon USA and application scientist at ION-TOF USA, companies specializing in surface science (NY, USA)
- **Prof. Armin Gölzhäuser:** founder, scientific advisor, inventor of CNMs, head of the research group “Physics of supramolecular systems and surfaces” at Bielefeld University with approx. 10 scientists, and first class laboratory and R&D facilities (HIM, XPS, STM, ...)
- **Jörg Vandreier:** founder, management consultant, former CFO of SAP Systems Integration AG, itelligence AG, and IDS Scheer AG

- **Gründerfonds Bielefeld-Ostwestfalen, managed by eCAPITAL entrepreneurial Partners AG, Münster:** invested since May 2014

Gründerfonds Bielefeld-Ostwestfalen

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Funded by the European Union

Carbon Nanomembranes (CNMs)

CNM TECHNOLOGIES

A New and Unique Class of Material

CNMs are molecular thin, i.e. 1 nm, man-made polymeric membranes.

Household plastic wrap covering a salad bowl

Area covered:
50 x 50 cm^2

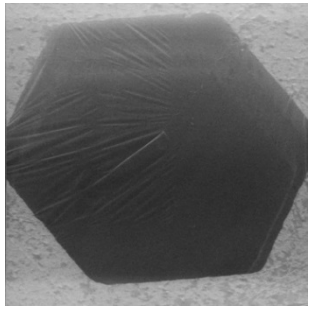
Film thickness:
10,000 nm

Reduction of all dimensions by a factor of 10,000

Free-standing CNM

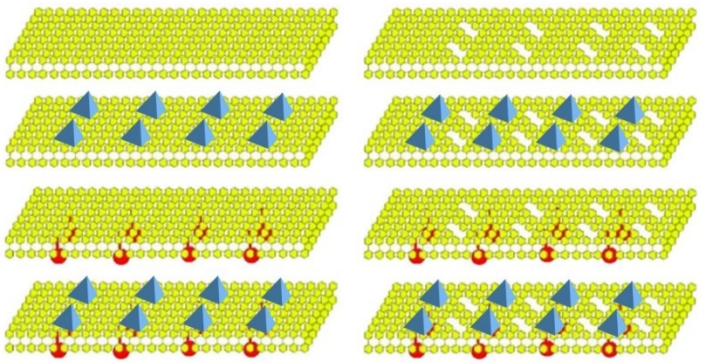
Area covered:
50 x 50 μm^2

Film thickness:
1 nm



Exemplary Properties

- Controllable chemical functionalization, porosity etc.
- Versatile and scalable manufacturing (from CMOS-compatible integration to large area membranes)
- CNMs are complementary to graphene, but can be transformed into graphene.



CNMs – a modular construction system for functional (biomimetic) nanomembranes

2D-Materials: CNMs vs. Graphene

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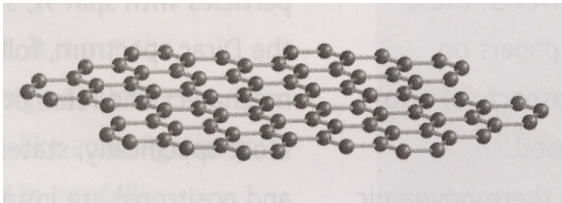
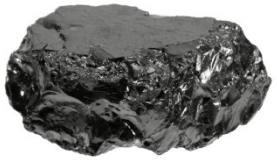
Comparison



CNMs		Graphene
▪ A pristine monolayer of CNM is highly permeable for water and nearly impermeable for any gases larger than He.	↔	A pristine monolayer of graphene is a perfect barrier for gases.
▪ CNMs can be easily chemically functionalized.	↔	Graphene cannot be easily functionalized and loses its properties during the process.
▪ Perforation can be intrinsically achieved during fabrication.	↔	Perforation has to be performed retroactively (e.g. via UV/ozone etching or ion bombardment).
▪ CNMs are elastic and follow the morphology of a substrate.	↔	Graphene is more brittle.
▪ CNMs are electrically insulating.	↔	Graphene has a unique electronic structure.
▪ CNMs can be transformed into graphene.	↔	Graphene cannot be transformed into CNMs.

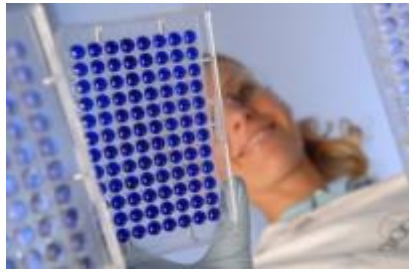
↔



Carbon Nanomembranes (CNMs)

CNM TECHNOLOGIES

A Platform Technology with a Huge Variety of Applications



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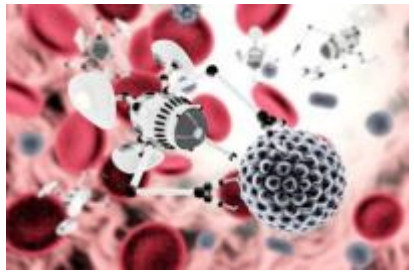
Medicine

- Diagnostics, lab-on-a-chip *
- Dialysis
- Tissue engineering
- Next generation sequencing **



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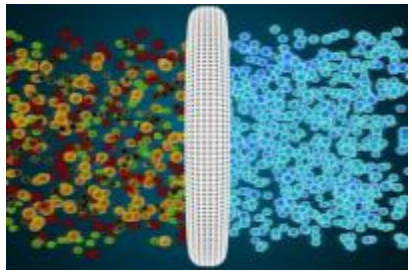
Nanotechnology

- TEM- and SPR-sample holder
- Nano tribology
- Nano fluidics
- Nano electromechanical systems (NEMS)



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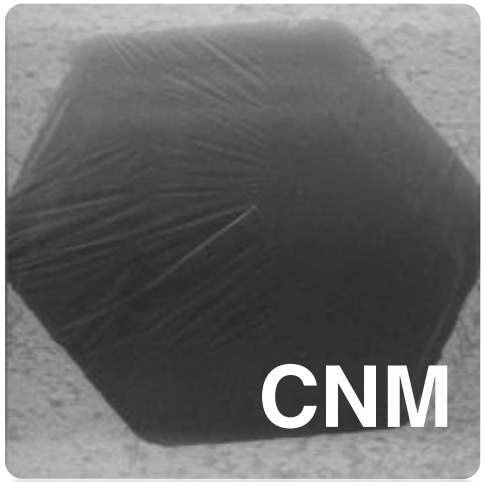
Membranes

- Filtration
- Separation
- Protective coatings
- Barrier layers



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Electronics

- Sensor technology
- Semiconductor manufacturing
- Flexible electronics
- Displays

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Energy

- Capacitors
- Batteries
- Fuel cells
- Electrolysis

* Current focus ** promising research results and/or interest from market

Application: Water Filtration

CNMs - Separation for the Future

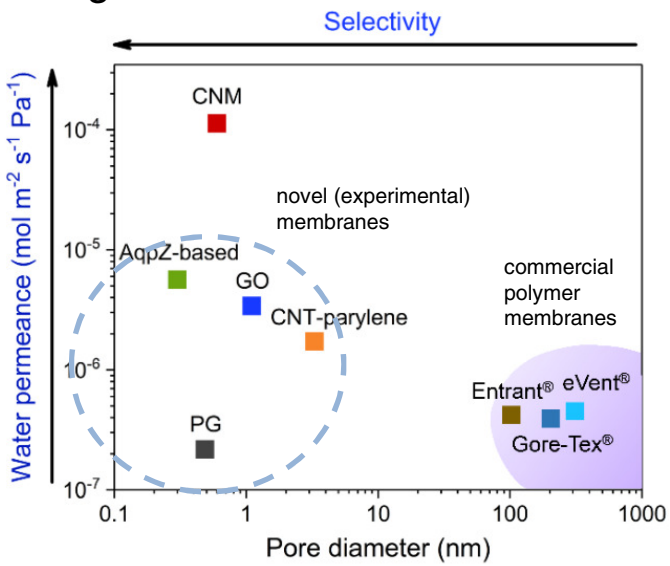
- purification of contaminated water (heavy metals, drugs, …)
- concentration of watery solutions (e. g. food industry, wastewater treatment)
- energy-efficient sea water desalination
- atmospheric water generation

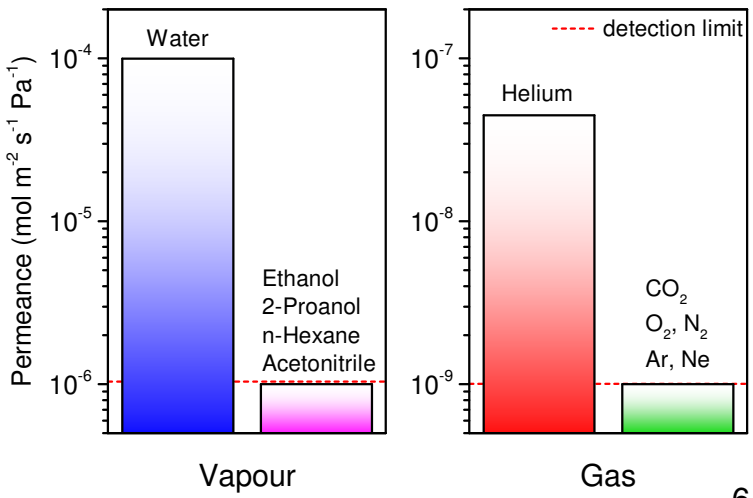
CNM as Highly Water-Permeable and Selective Membrane

Problem: Polymeric membranes (state-of-the-art as water filtration tools) often suffer from poor separation performances and their operation requires high pressure.

Solution: Water permeance several orders higher than other membranes

High selectivity (only water and Helium are transported)





Scaling of Fabrication

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Several options of already existing technologies are available for scaling of the three fabrication steps.

Preindustrial fabrication based on batch-production (to be implemented in the coming year)

- Capacity — a few 10.000 m²/year
- Size — 30 x 30 cm² (or other)
- Price — a few 10 €/m²

Concept for high volume manufacturing based on roll-to-roll process

- Size — variable
- needs development on machine side

Concept for manufacturing based on organic vapour phase deposition (OVPD)-process

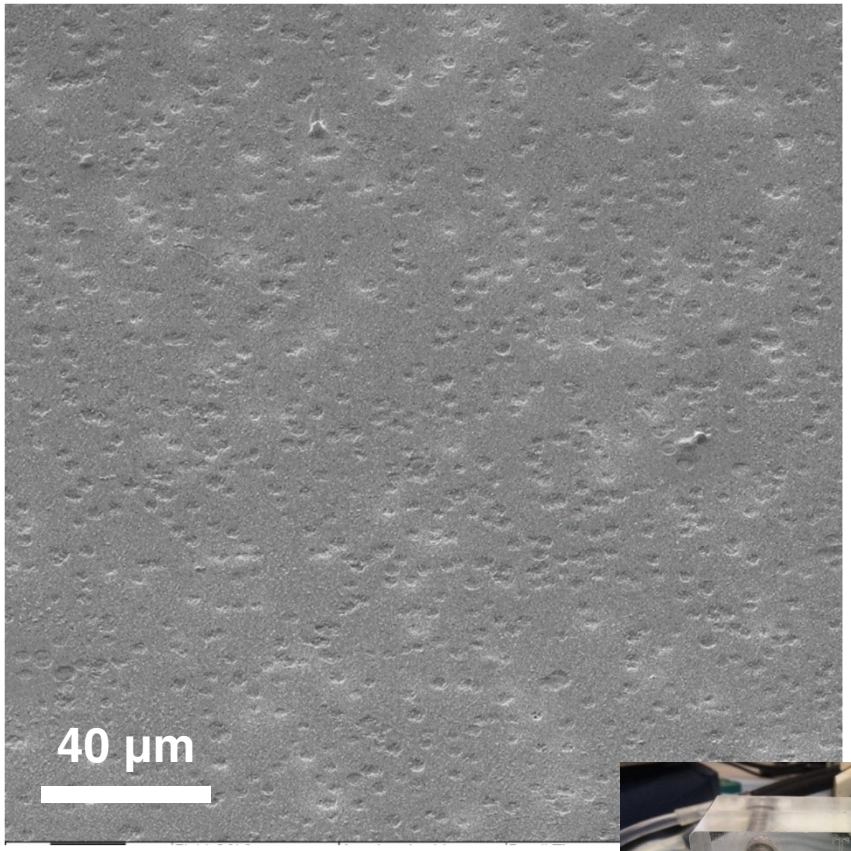
- Size — 300 x 300 mm² or 300 mm ∅
- machine for SAM-Production and Crosslinking “available”

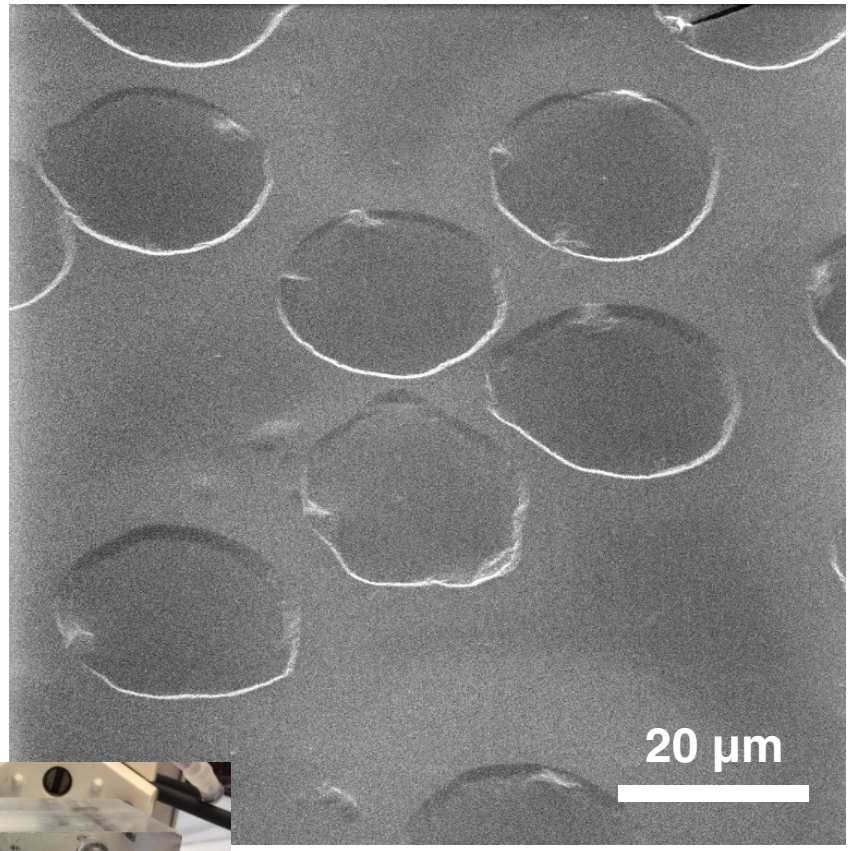
* US 8,377,243 B2, EP 2 144 711 B1

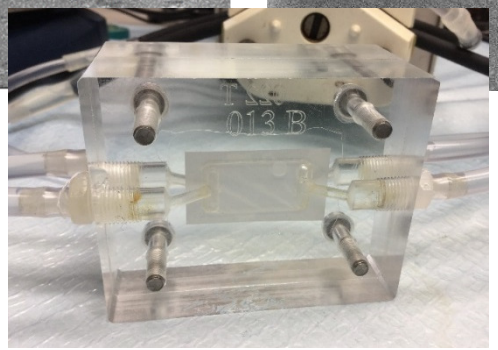
CNM-Based Hybridmembranes

Free-Standing CNMs Supported by Porous Polymer

2 µm Diameter of freestanding CNMs 20 µm







Test of “large-area” membrane (approx. 2 cm²) for forward osmosis (FO) applications

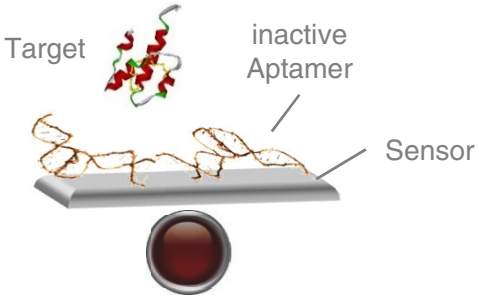
Application Example: Bio-Sensors

CNMs for Functional Immobilization of Oligonucleotides

- point-of-care diagnostics
- chemical and biological sensors
- next generation sequencing

CNM as Functionalization Layer for Oligonucleotide Immobilisation

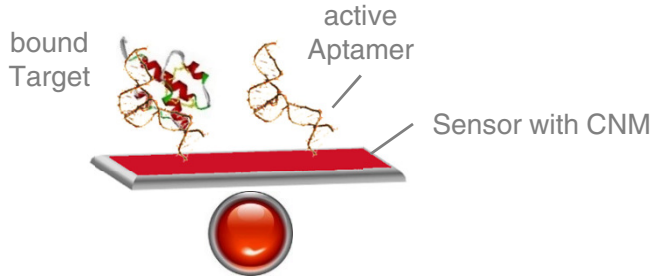
Problem



- Oligonucleotides can adopt complex 3D-structures, which can bind a target with high affinity and specificity (e.g. aptamers)
- Immobilization of oligonucleotides on a surface often leads to loss of their structure

⇒ without structure: no target recognition

Solution: Use of CNMs



- Easy and fast immobilization of oligonucleotides via click-chemistry
- Immobilized aptamers maintain their 3D-structure and therefore their specific target binding properties
- Interaction of bound targets with surface-sensitive sensors possible due to 1 nm thickness of CNM

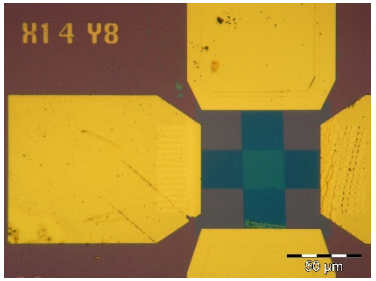
Further Applications

Potential is not Exhausted

Energy Storage

CNM as ultrathin Carbon-based dielectricum

- Component for energy storage:
  - Energiewende
  - E-Mobility
- Flexible Electronics
- Wearables



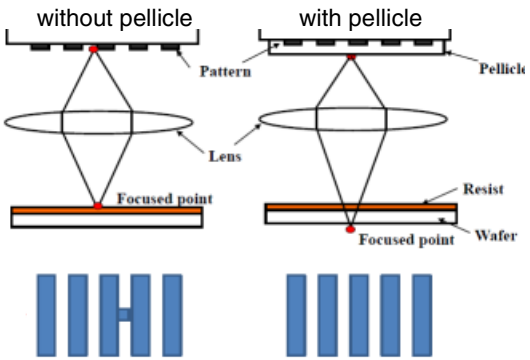
CNM as Surface-Electrolyte-Interface-Layer

- Next generation battery technology

Pellicle for EUV-Lithography

Problem

- no satisfying pellicles available, since no material is transparent
- particles of even some nm size cause defects on wafer

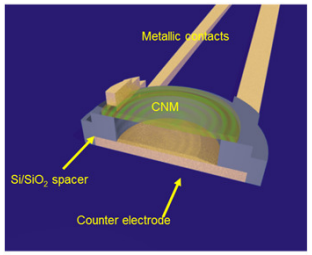


Solution: Standard CNM as EUV-pellicle meets many specifications of manufacturer

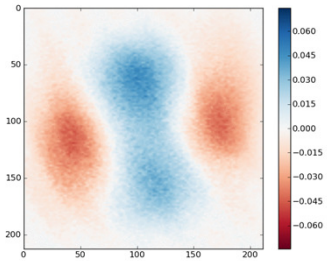
"Nanomicrophone"

CNM as oscillating membrane allows smallest design

schematic



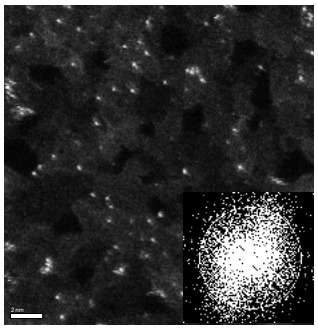
proof-of-concept: vibrational modes of a CNM



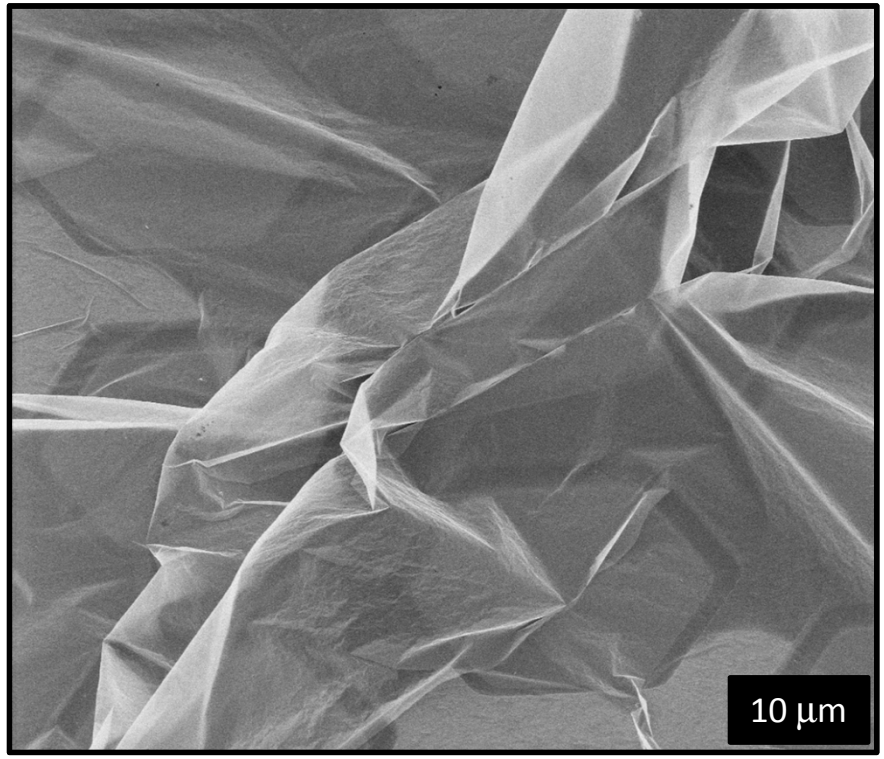
Sample Support for TEM

Advantages CNM

- lowest background signal
- homogeneously thin
- chemical functionalization possible



Single atom resolution



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