Graphene

tutorial

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SNI
SWISS NANOSCIENCE INSTITUTE

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6. Ballistic graphene (pseudo-spin optics, p-n-junction & Klein tunneling)
7. Pseudodiffusion (minimum conductivity and shot-noise at the CNP)
8. Outlook: further topics such as optics, mechanics

1. Introduction

Carbon

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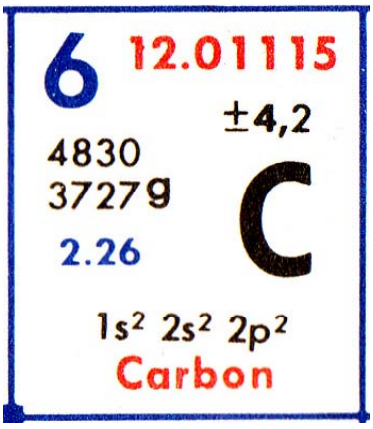

Schmelzpunkt 3727 °C

Dichte 2.3 kg/Liter

Carbon = Coal (graphite)

Carbon = Diamond

man weiss seit 1797, dass Diamant reiner Kohlenstoff ist

Diamant ⟷ Kohle (Graphit)

Isolator

transparent

hart

Leiter

lichtundurchlässig

„weich“

Diamant ⟷ Kohle (Graphit)

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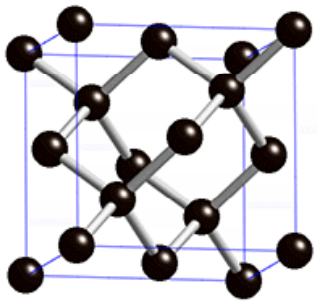
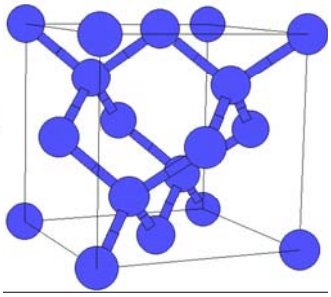
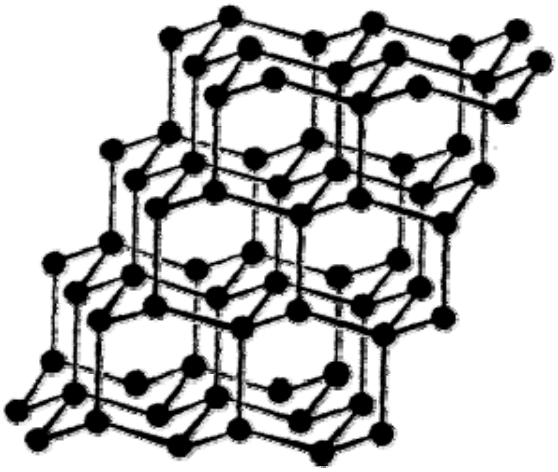
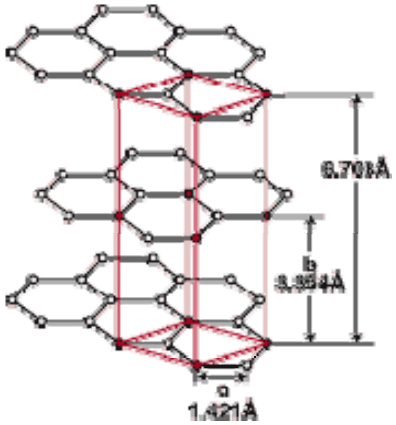
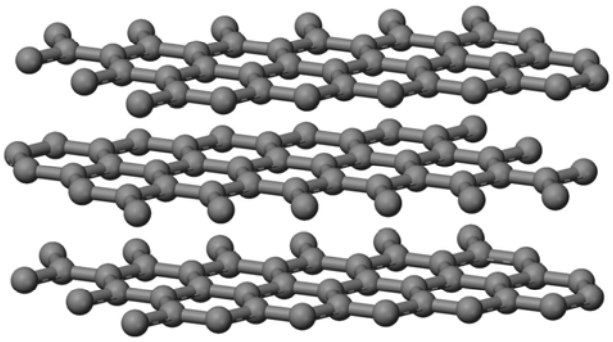




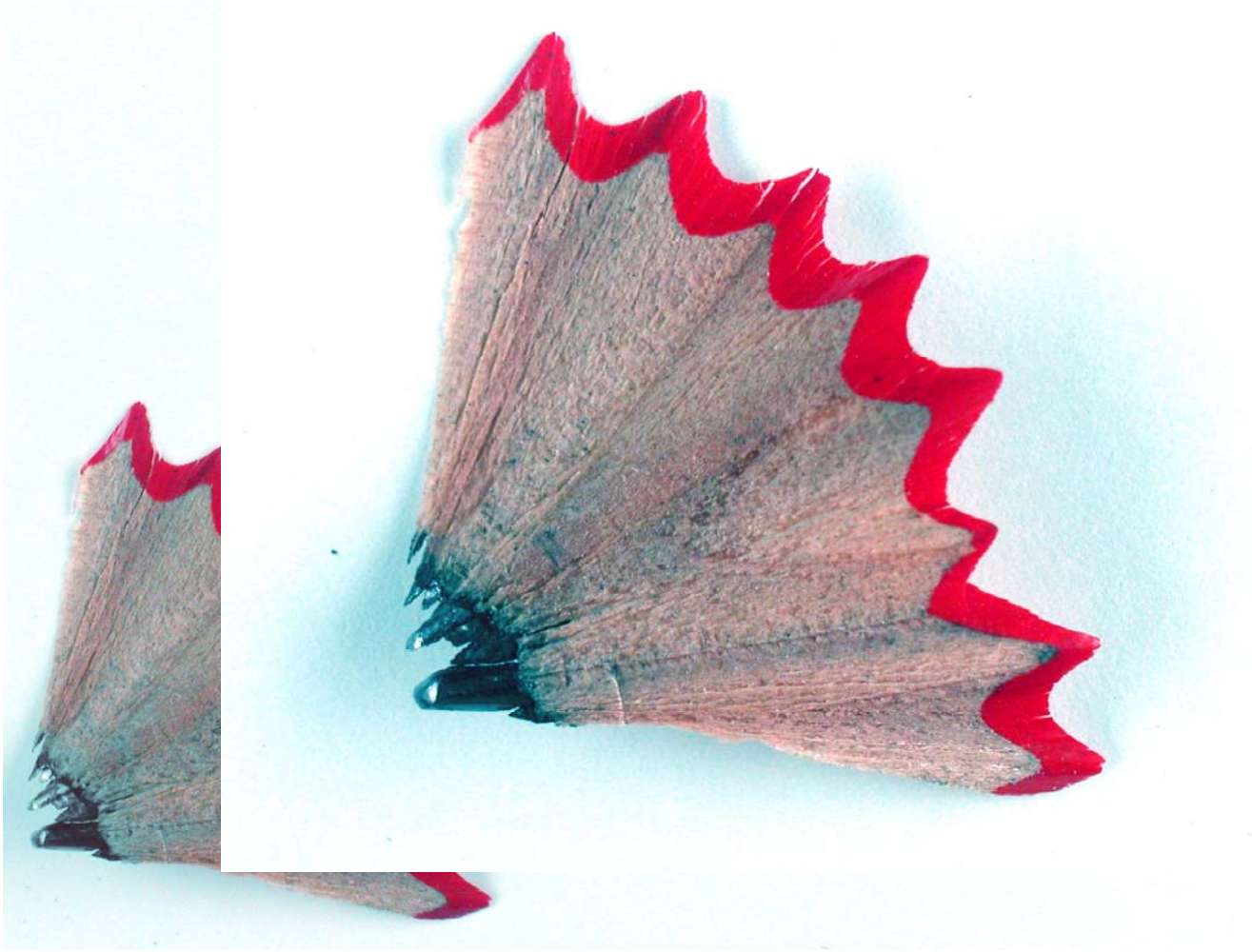


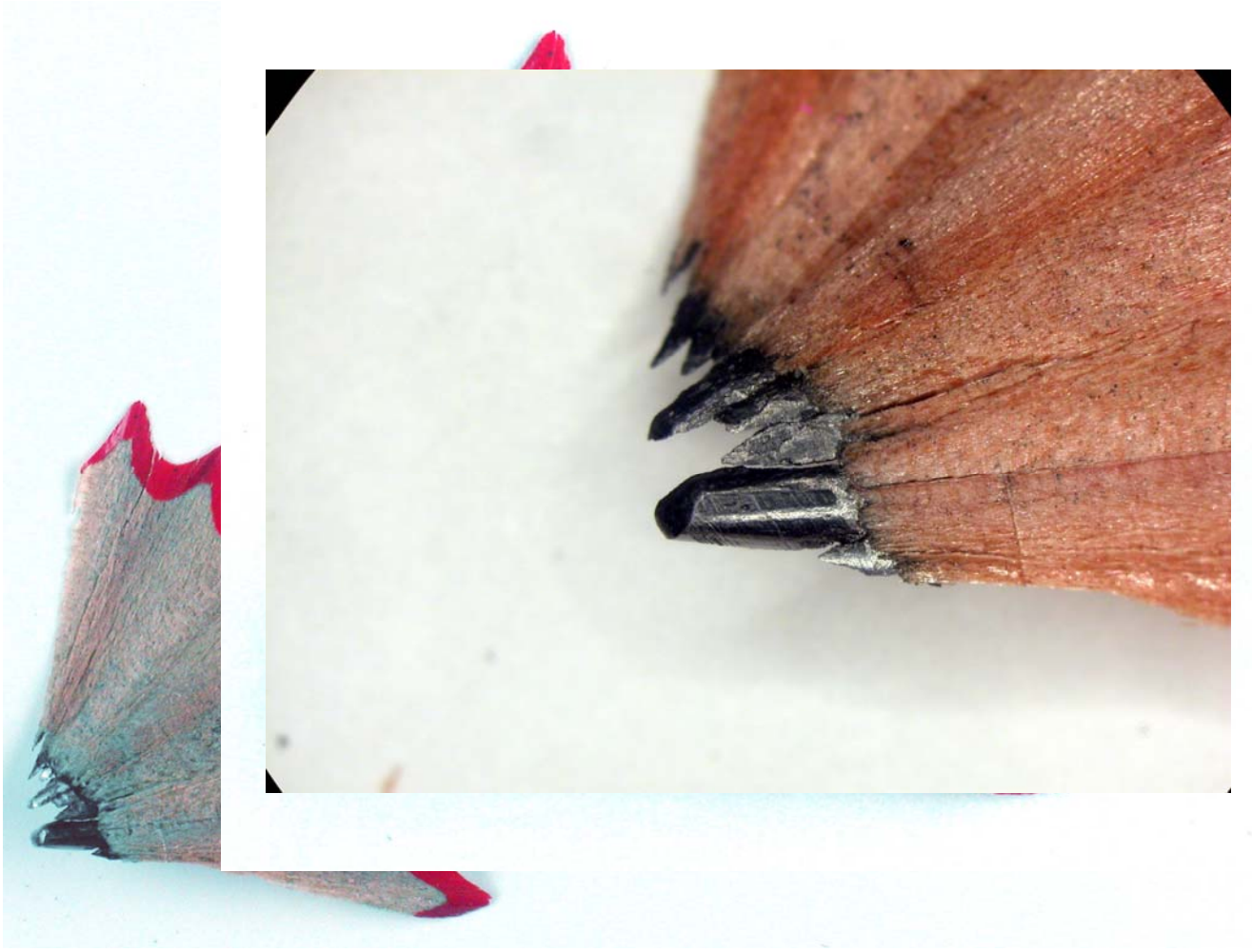
Diamant ⟷ Kohle (Graphit)

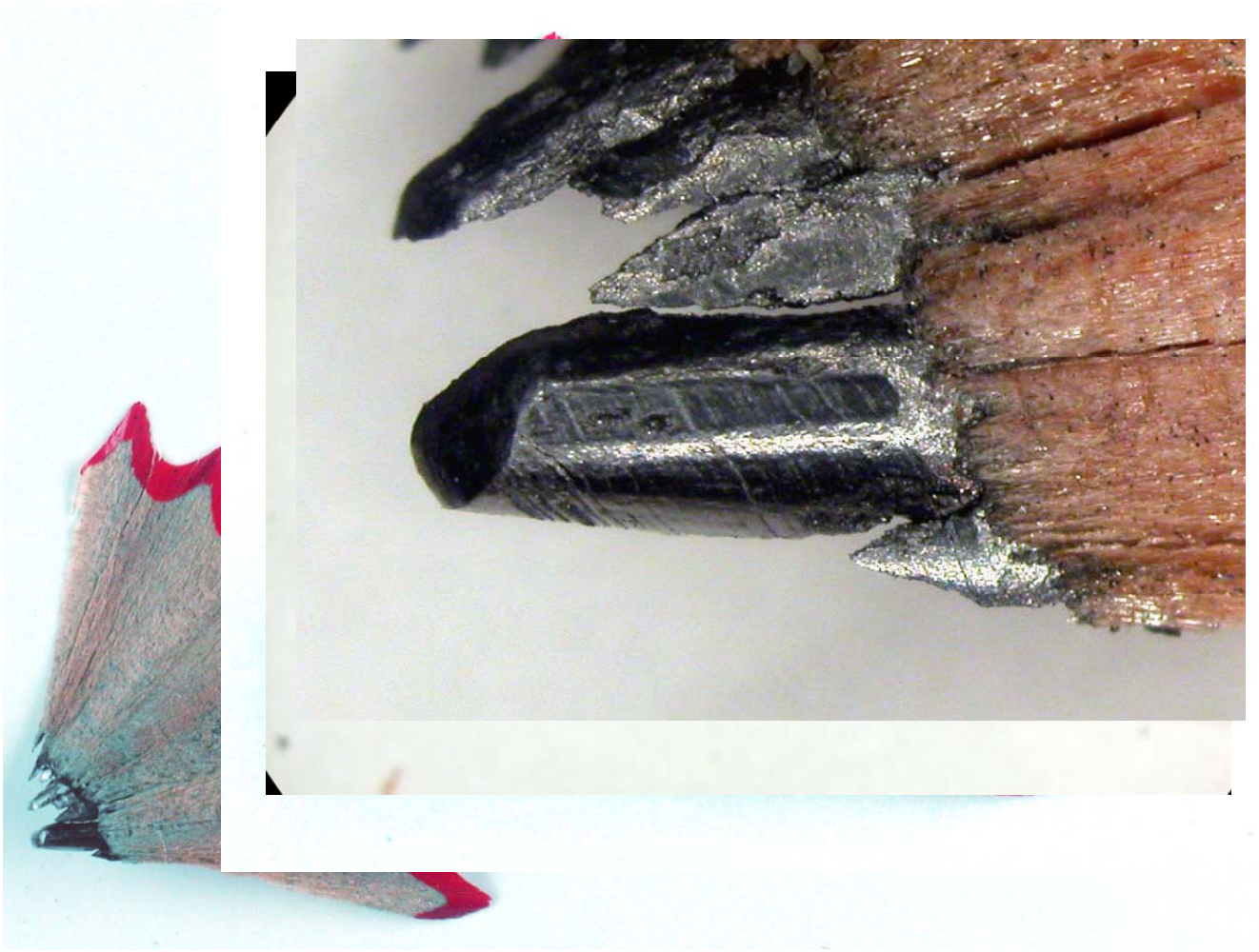




Bleistift im Mikroskop







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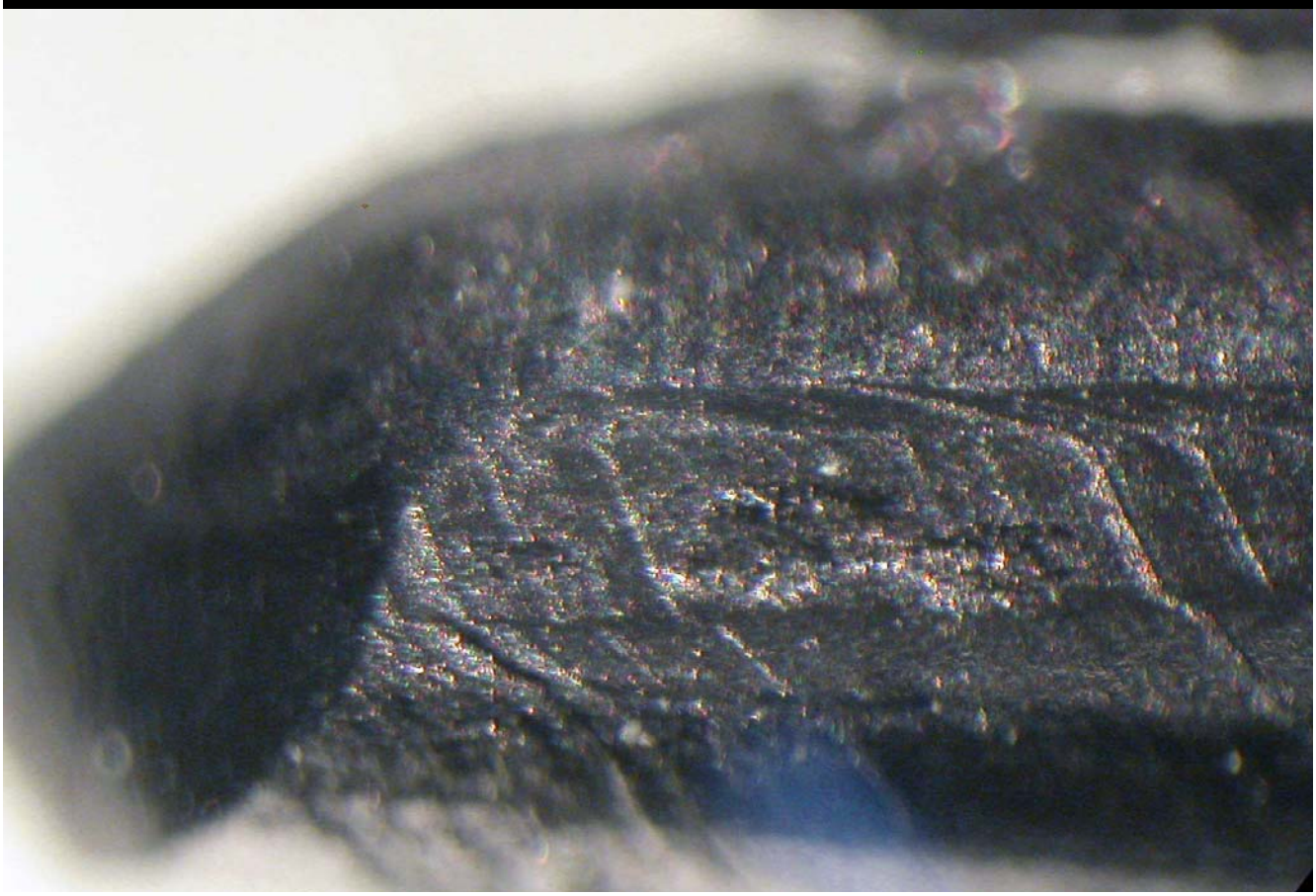

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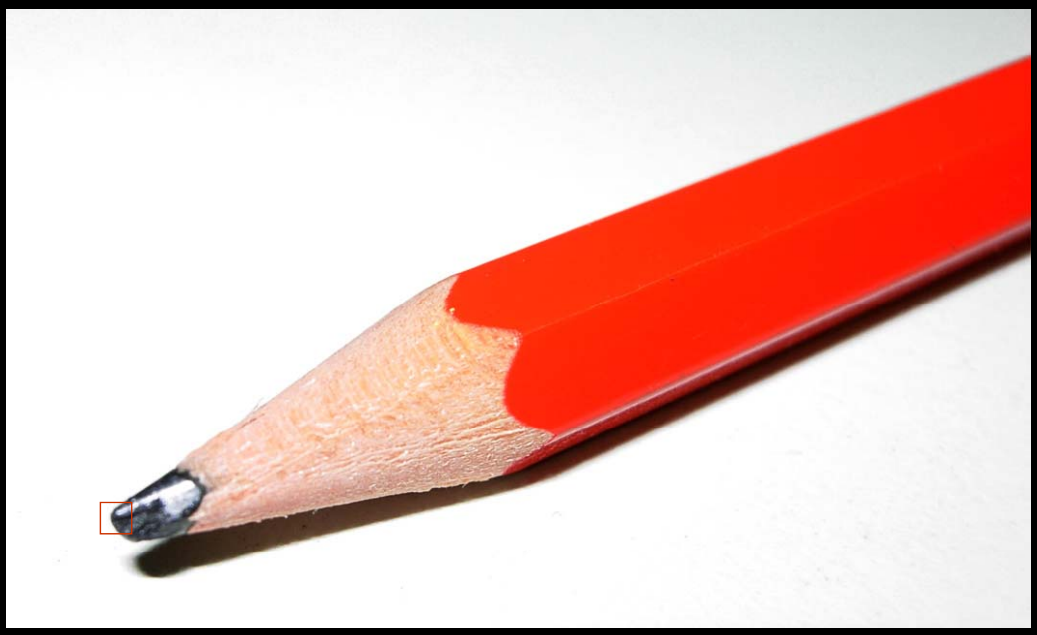

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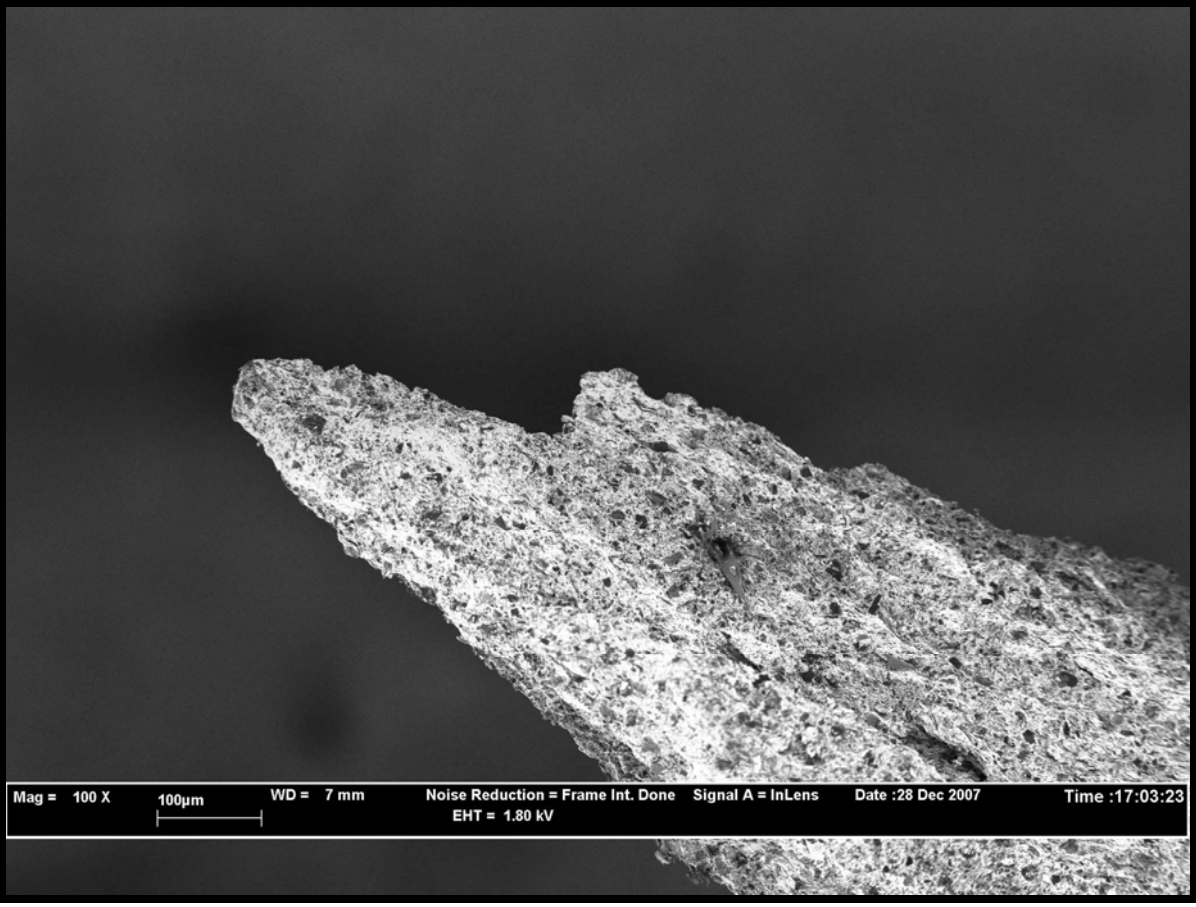

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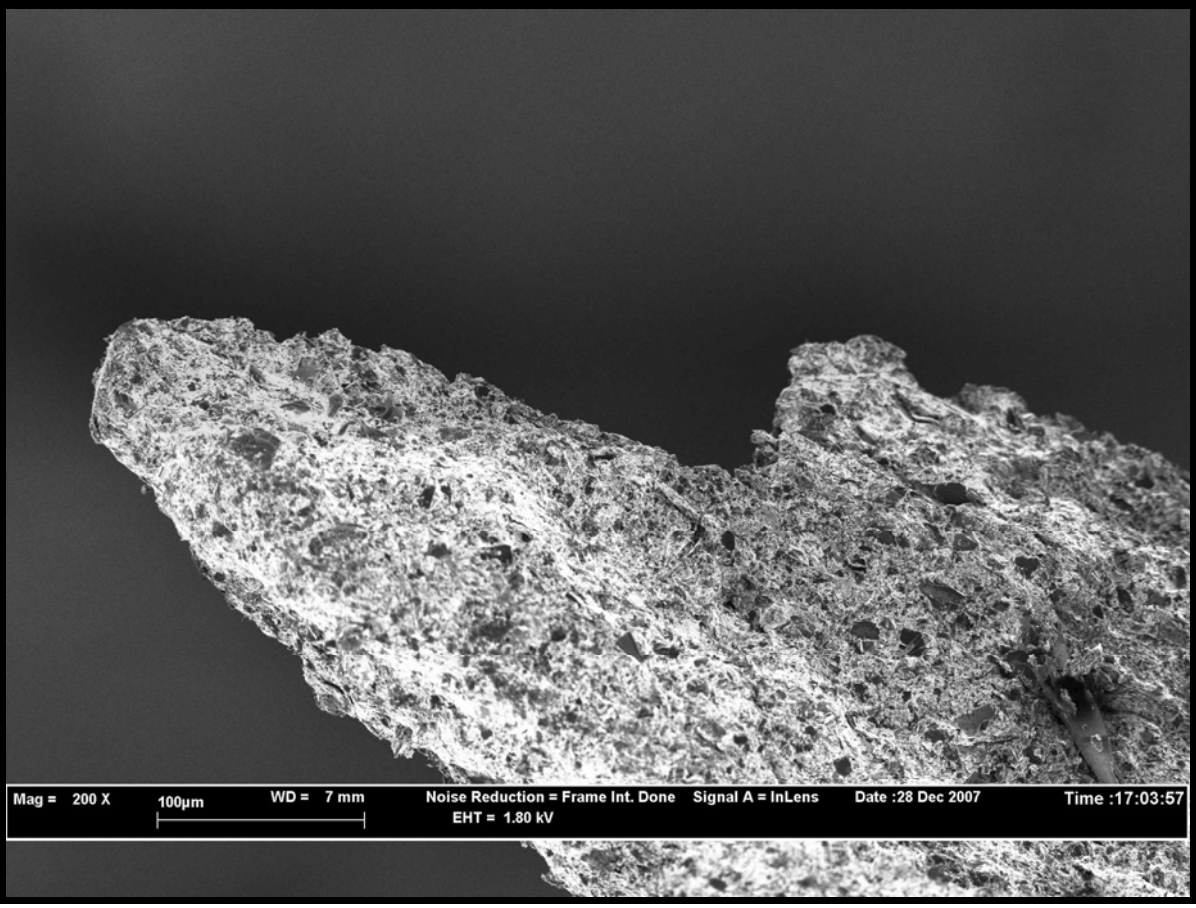

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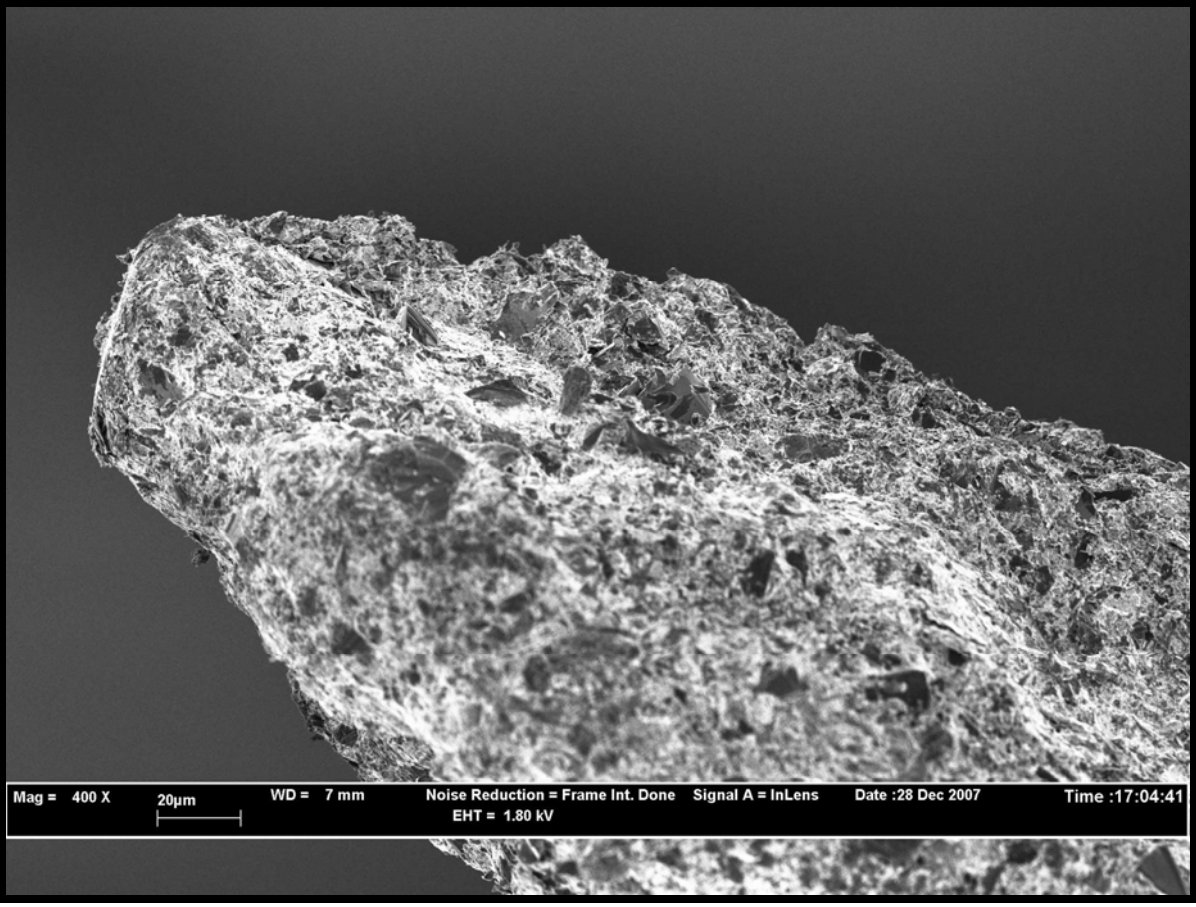

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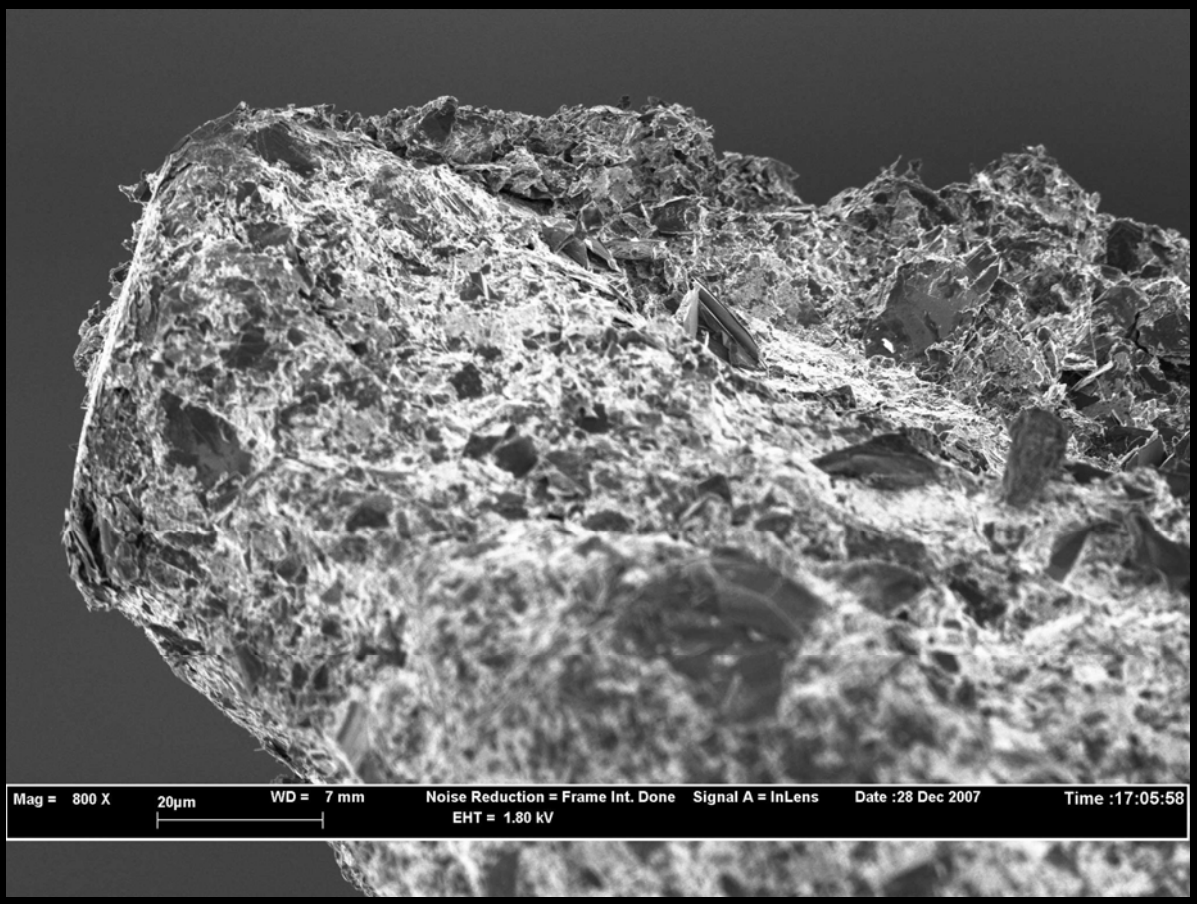

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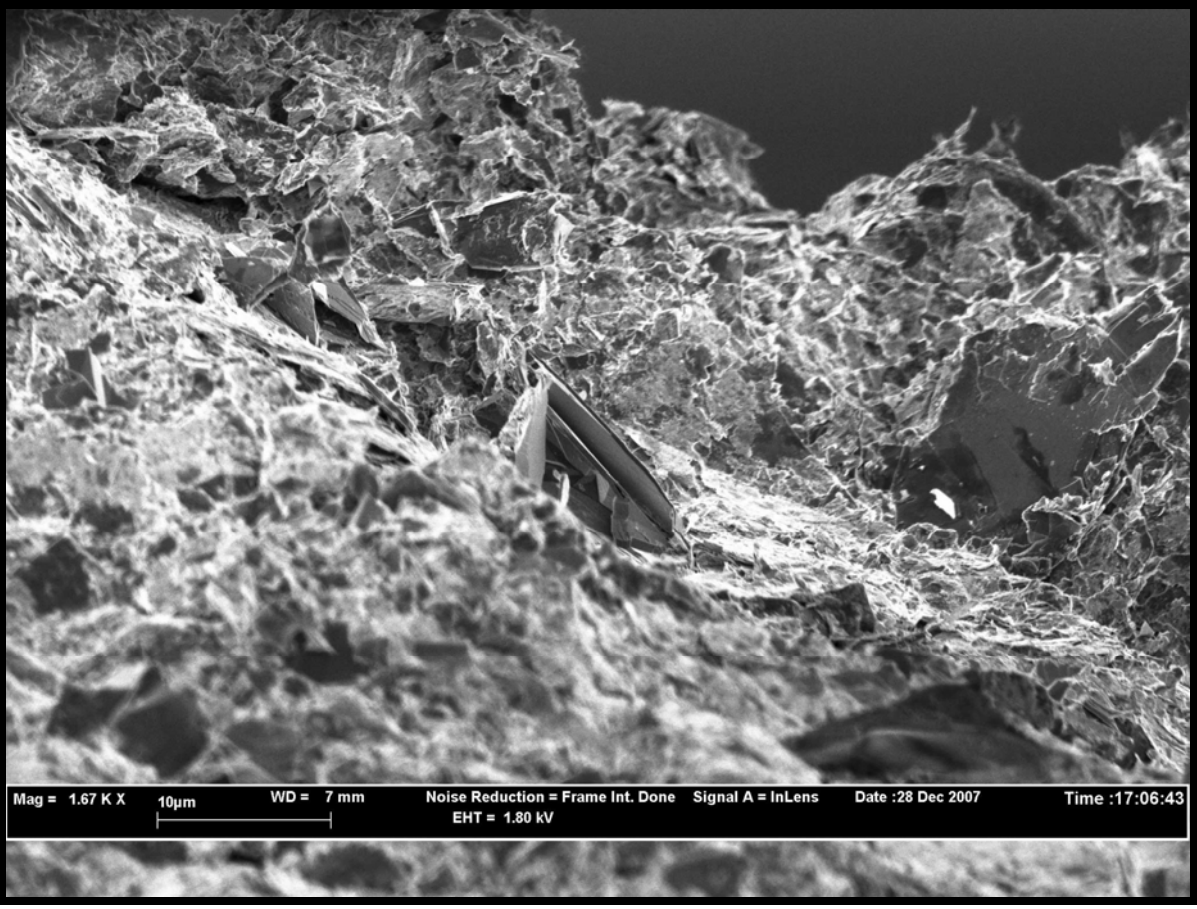

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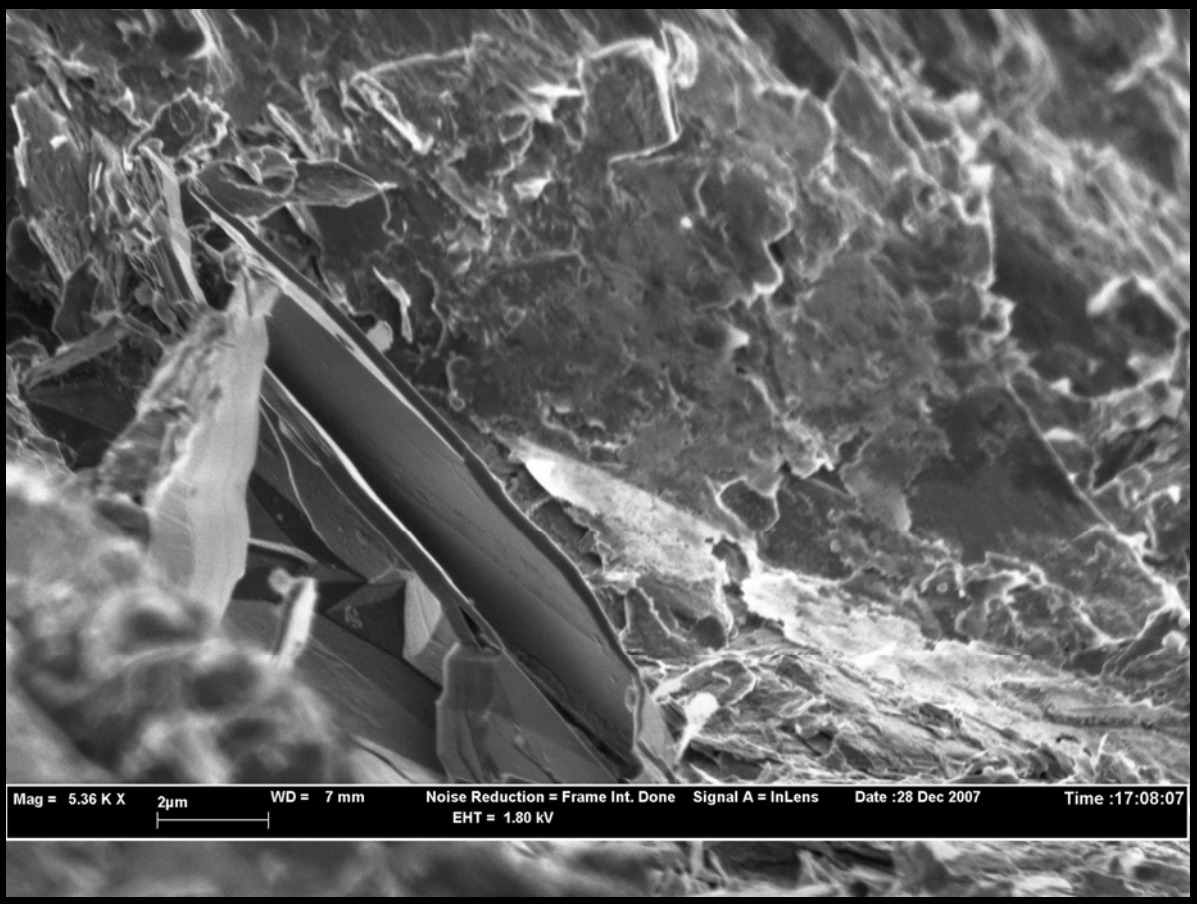

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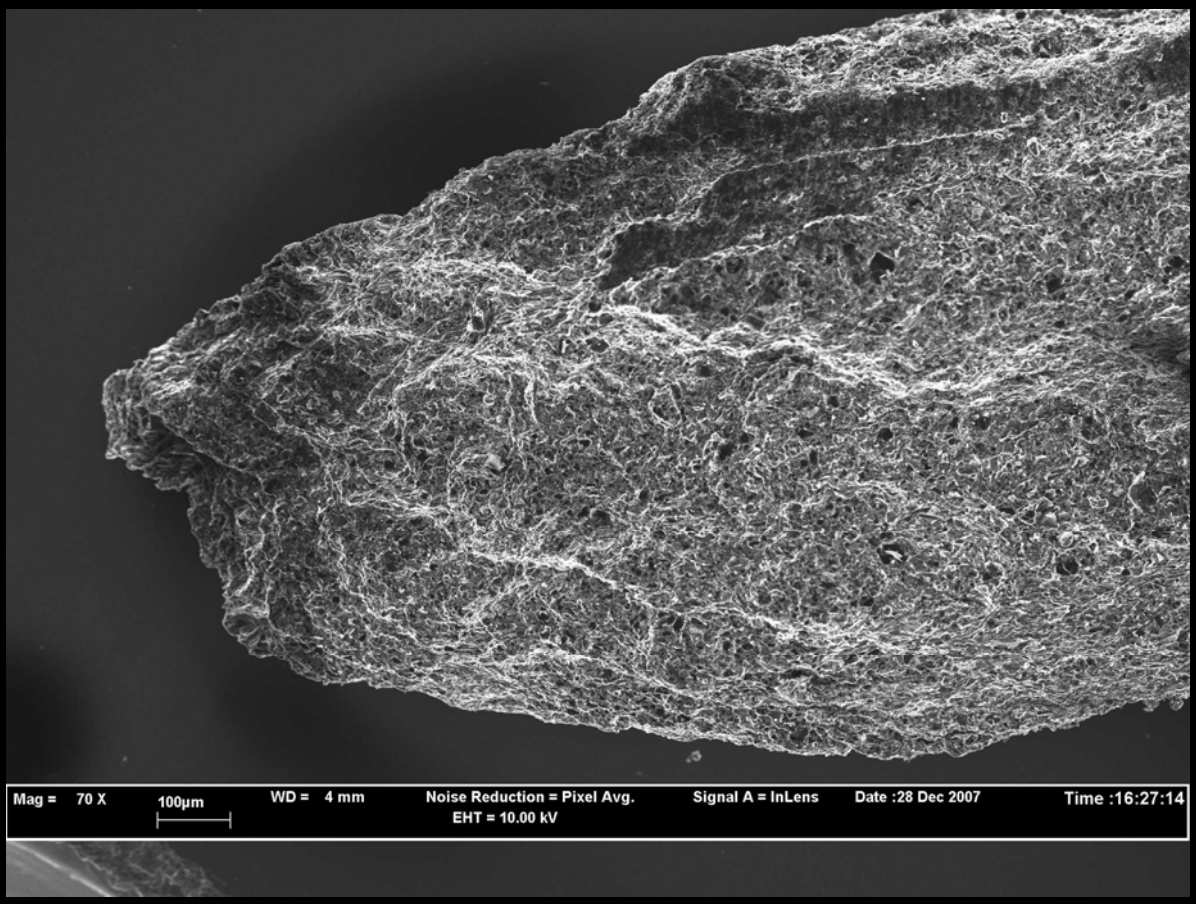

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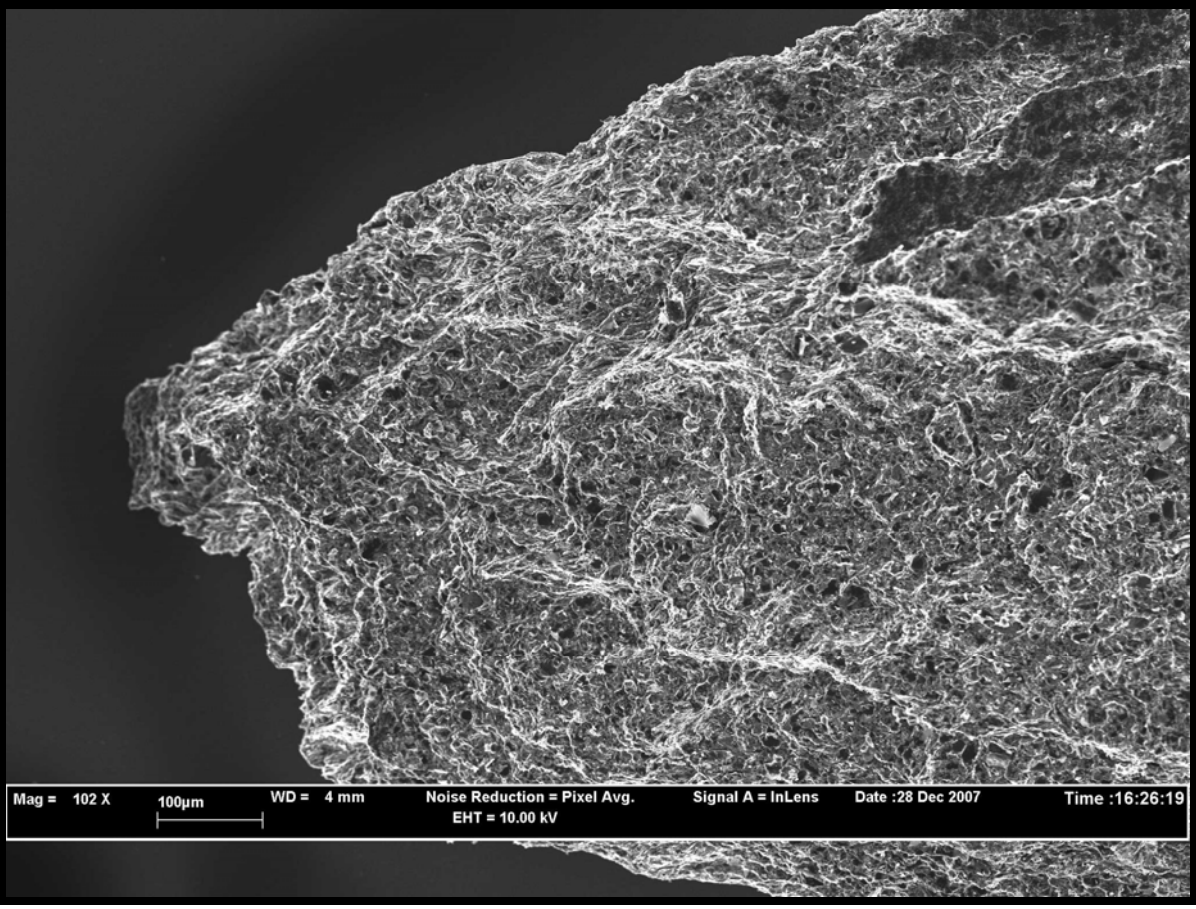

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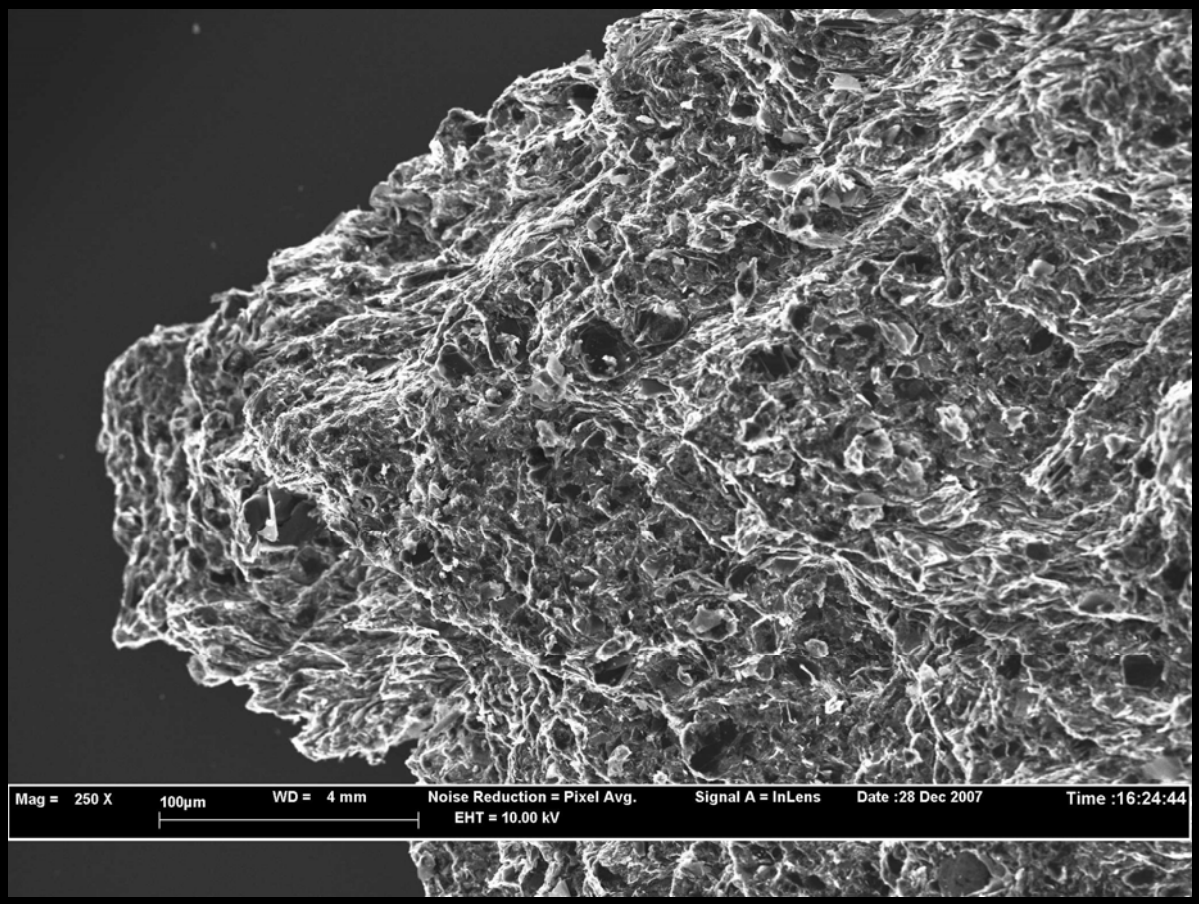

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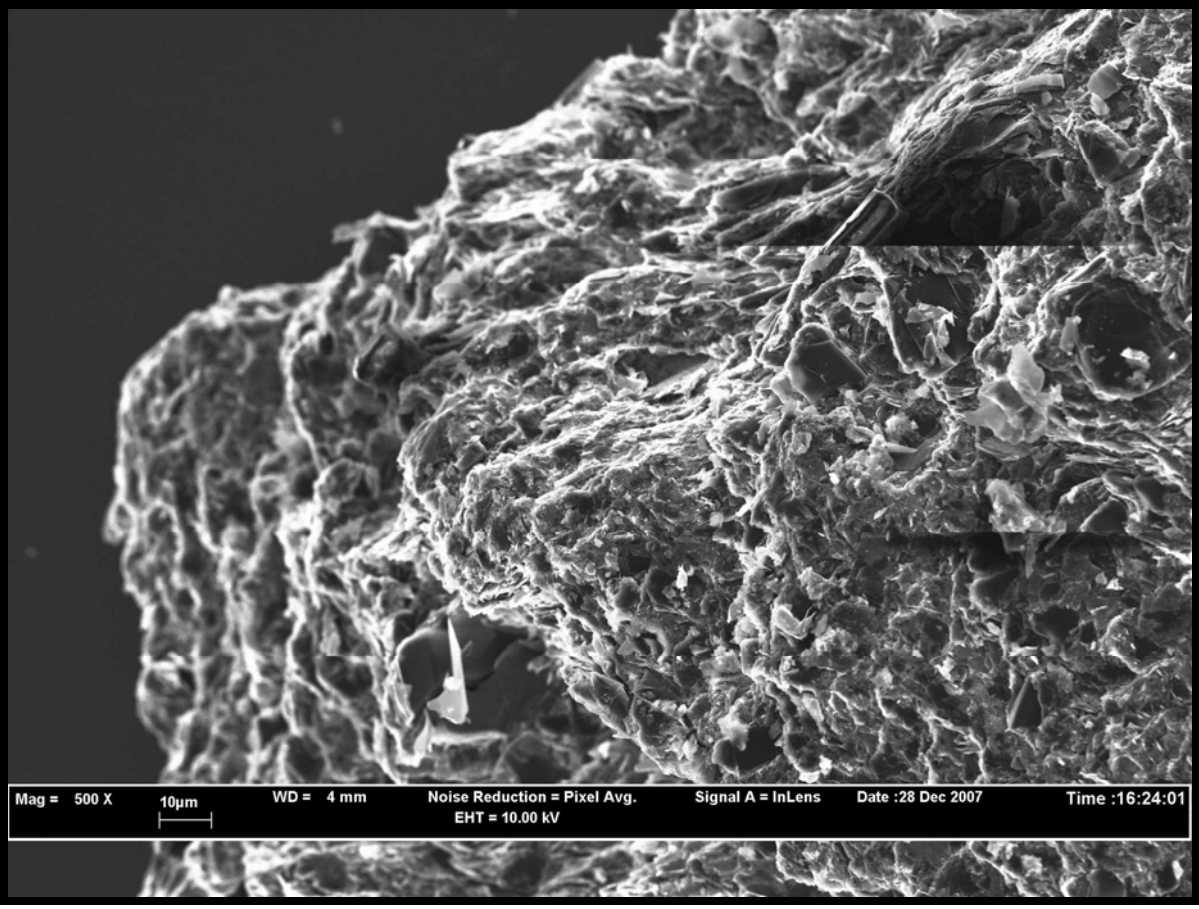

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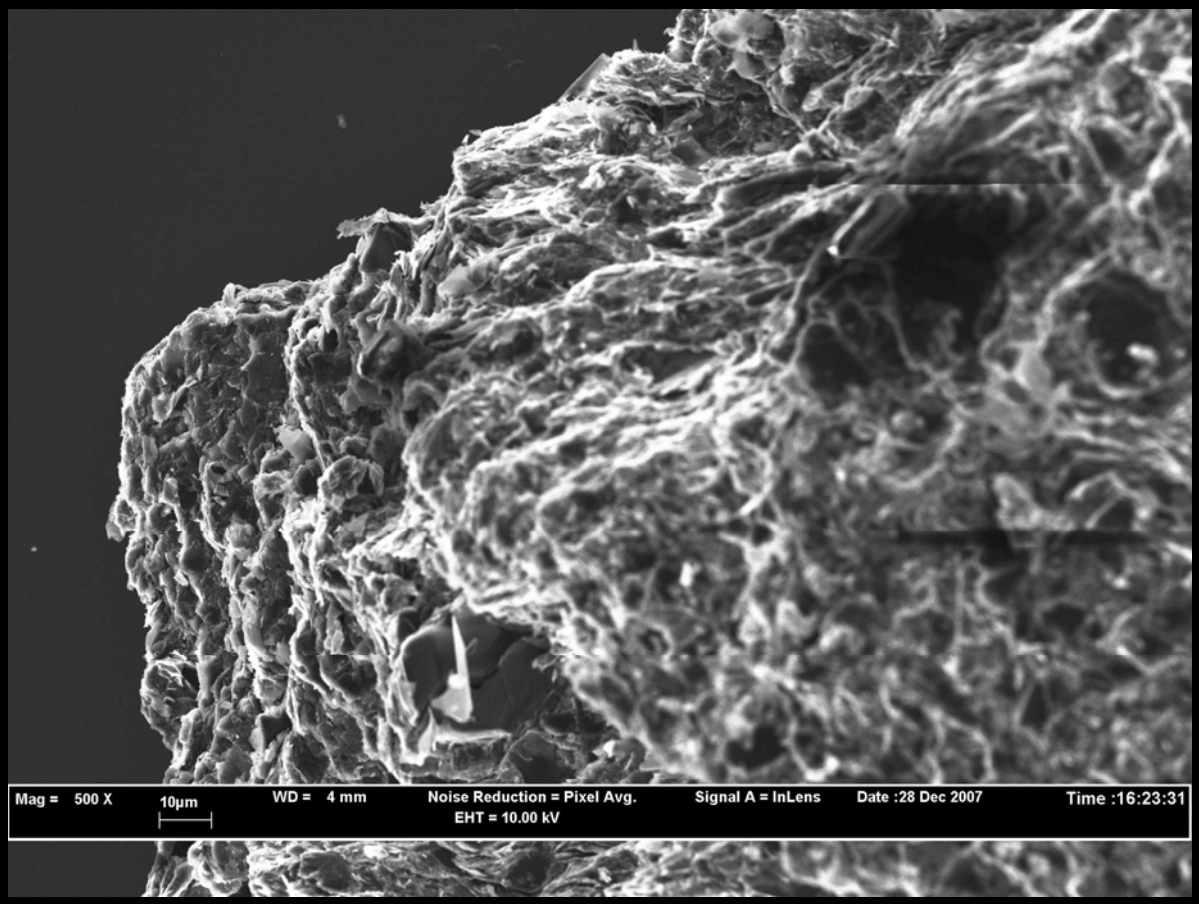

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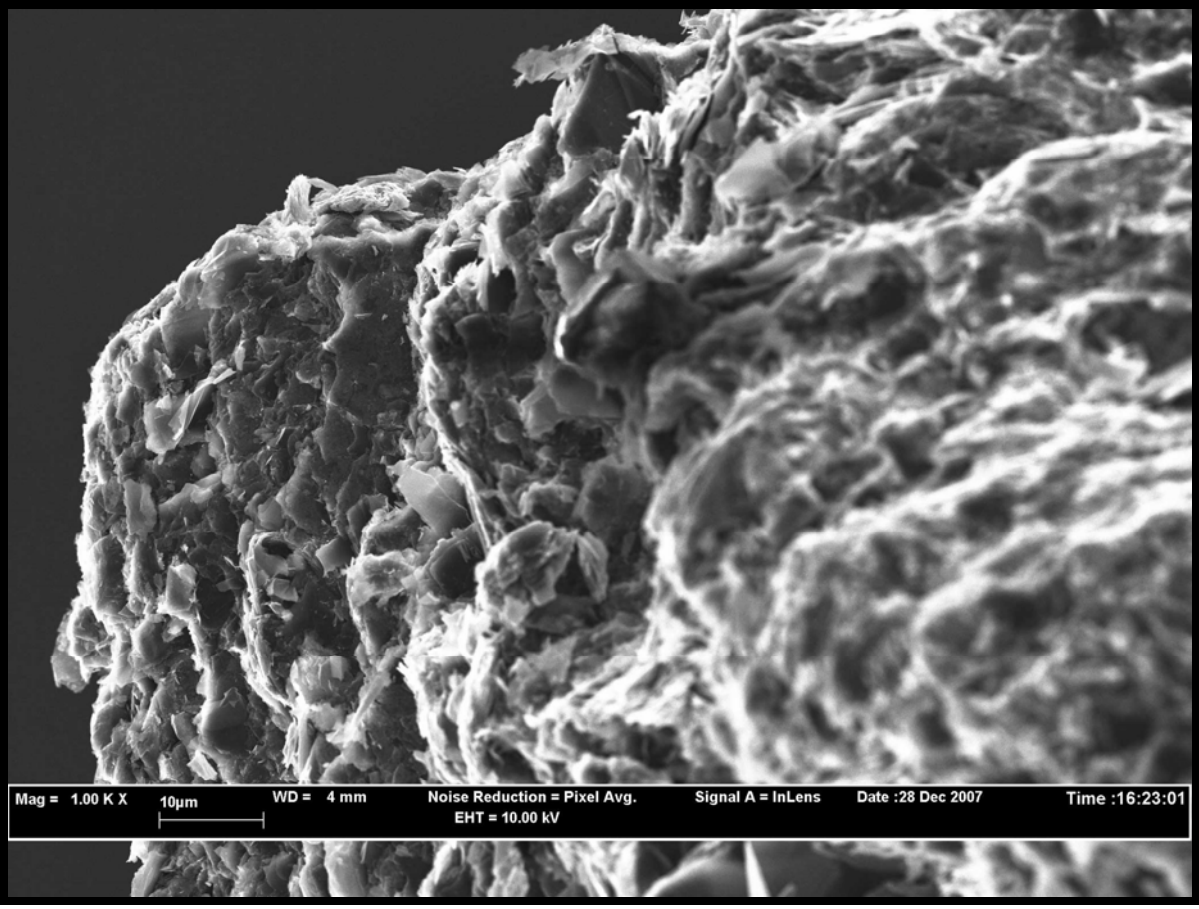

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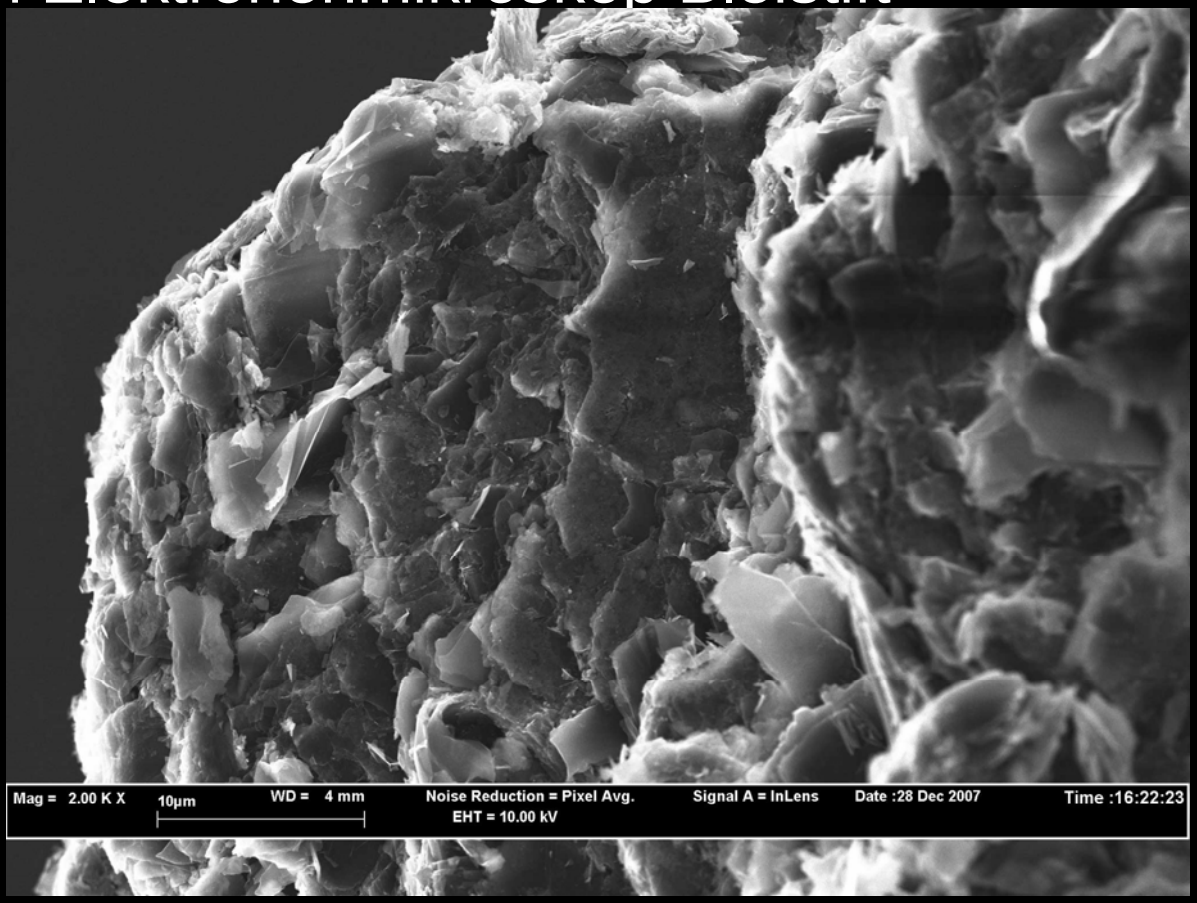

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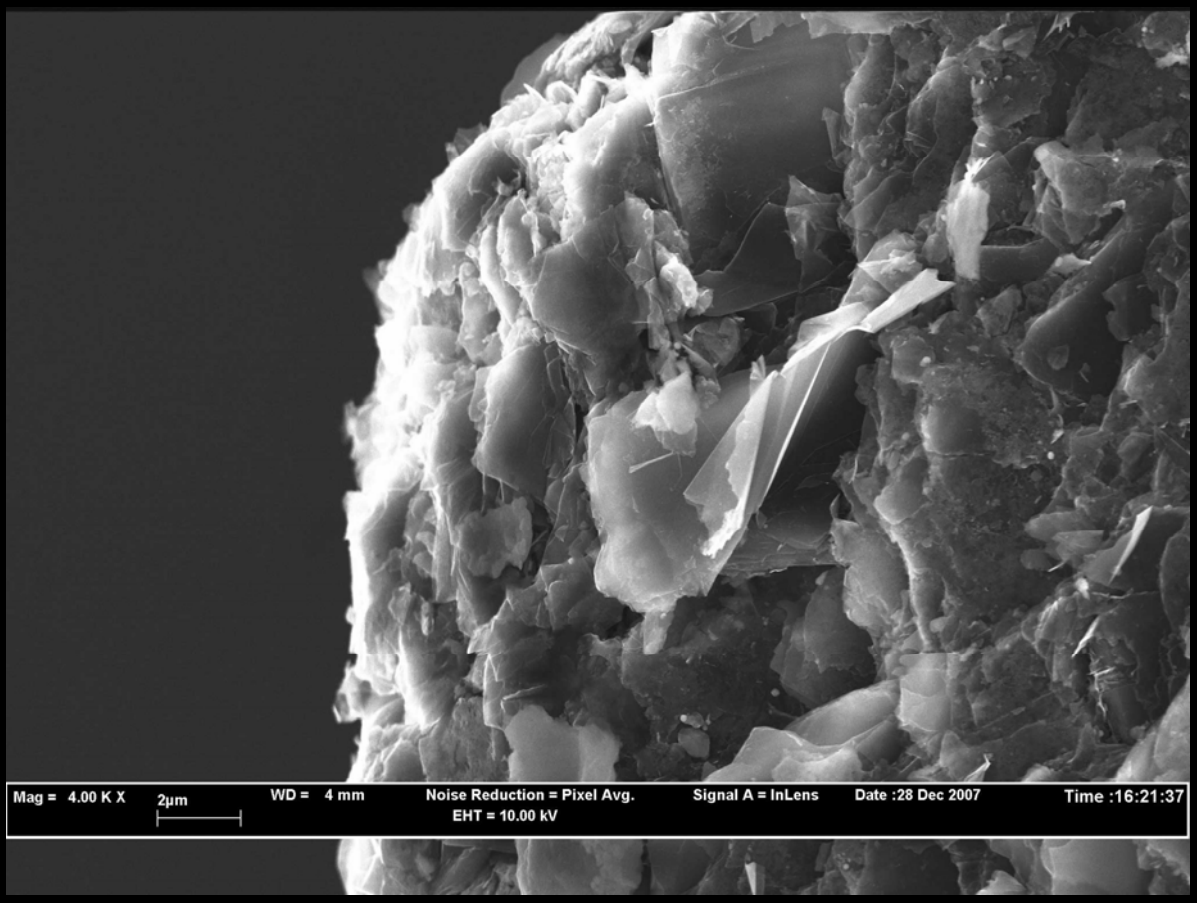

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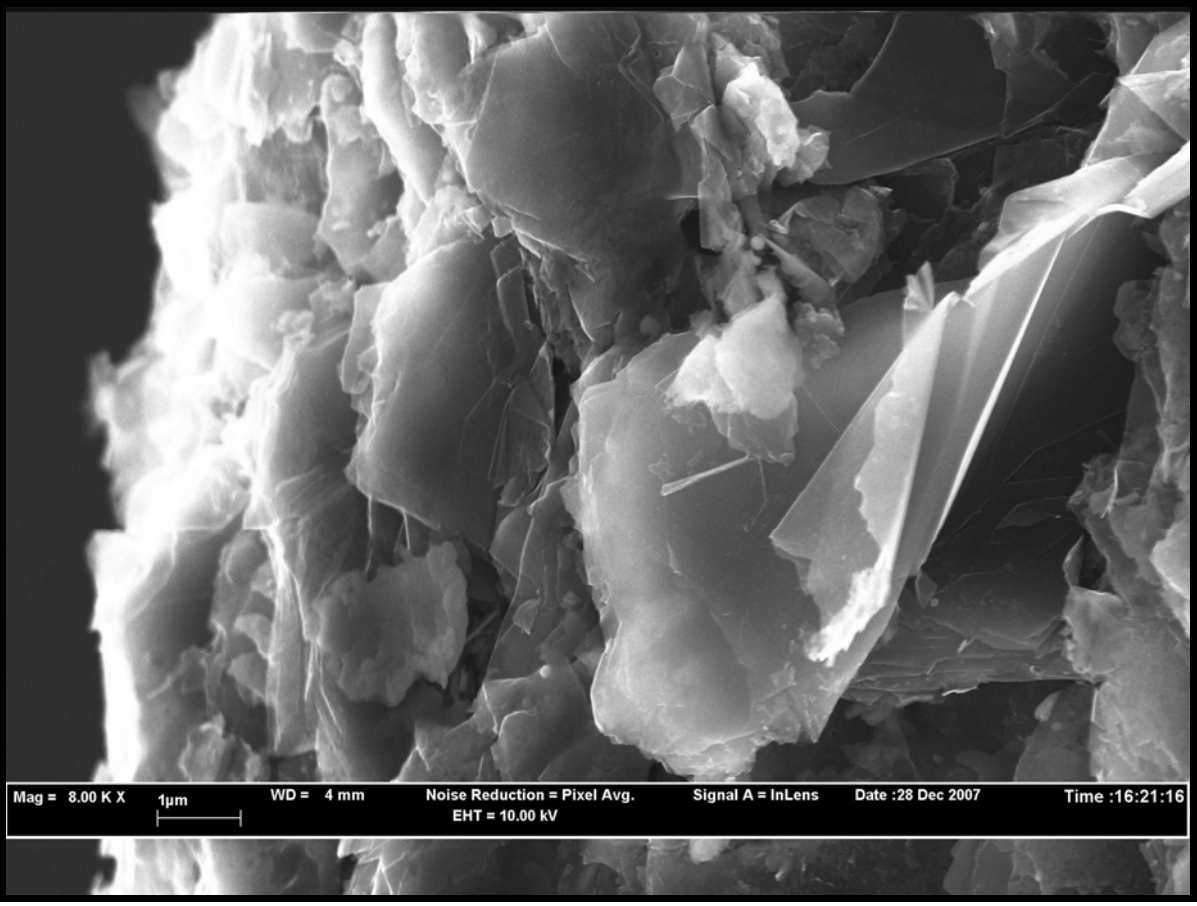

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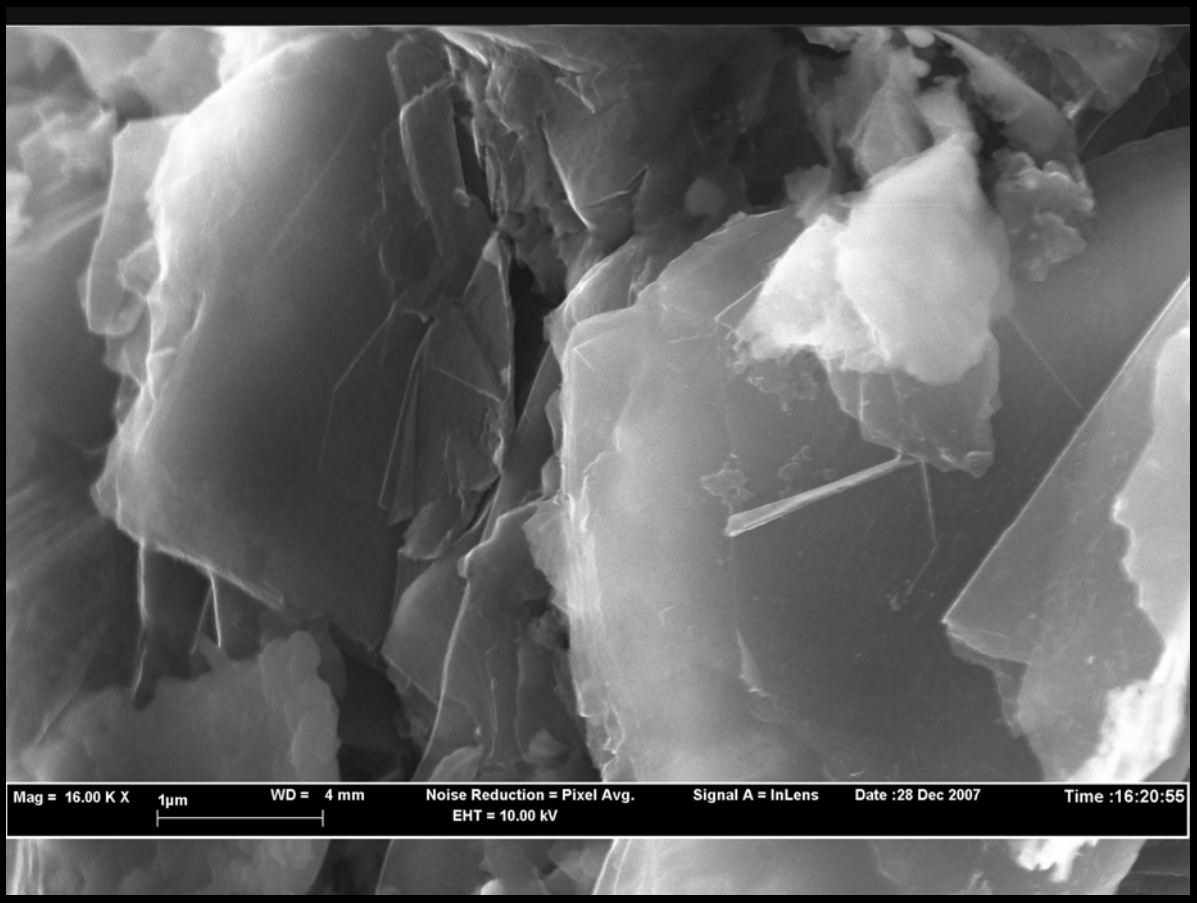

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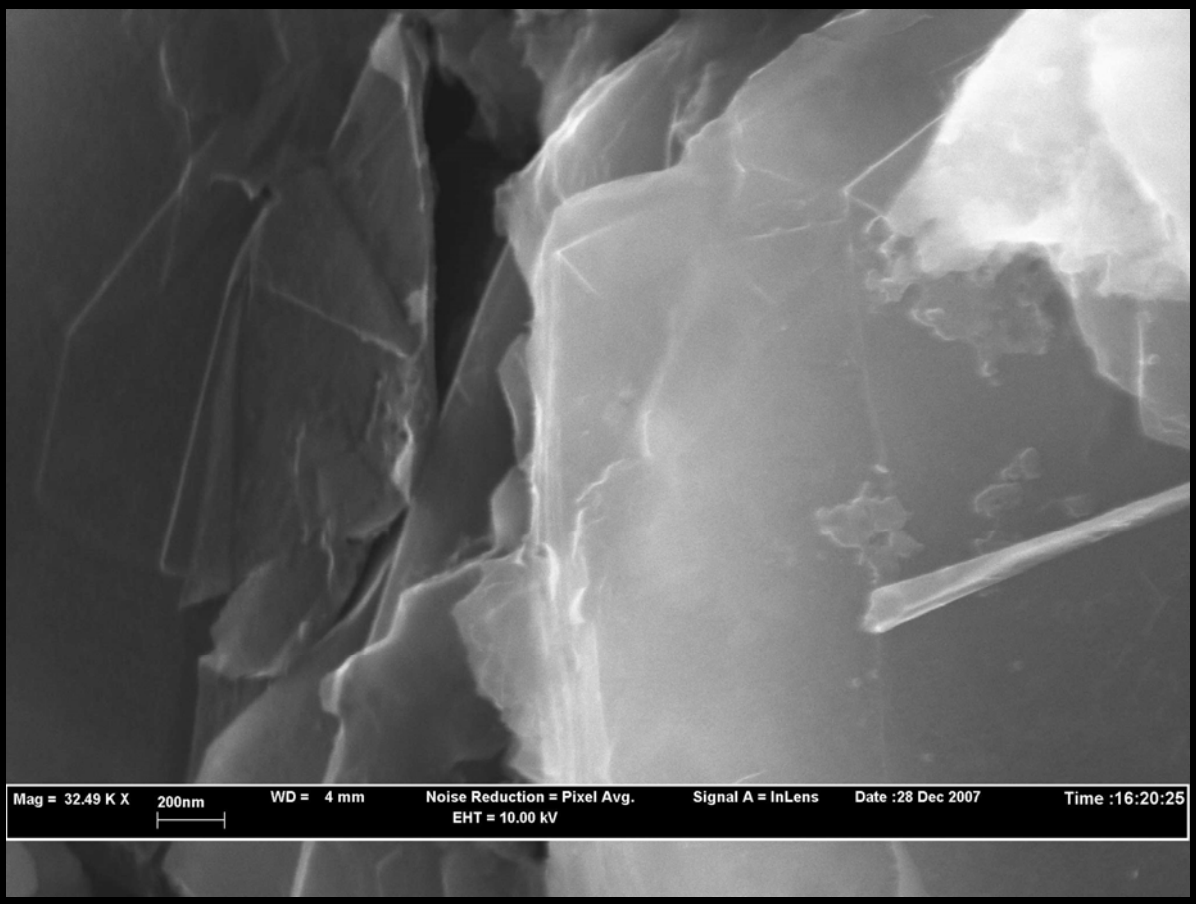

im Rastertunnelmikroskop

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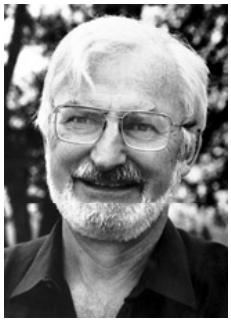
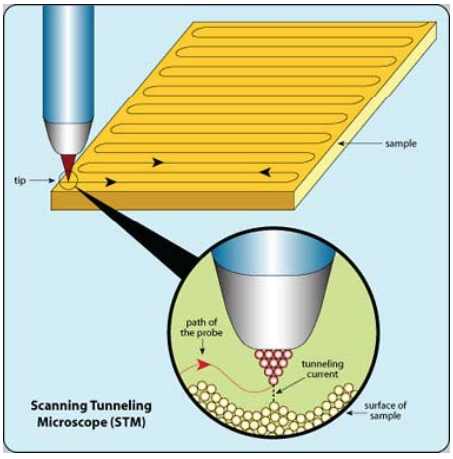
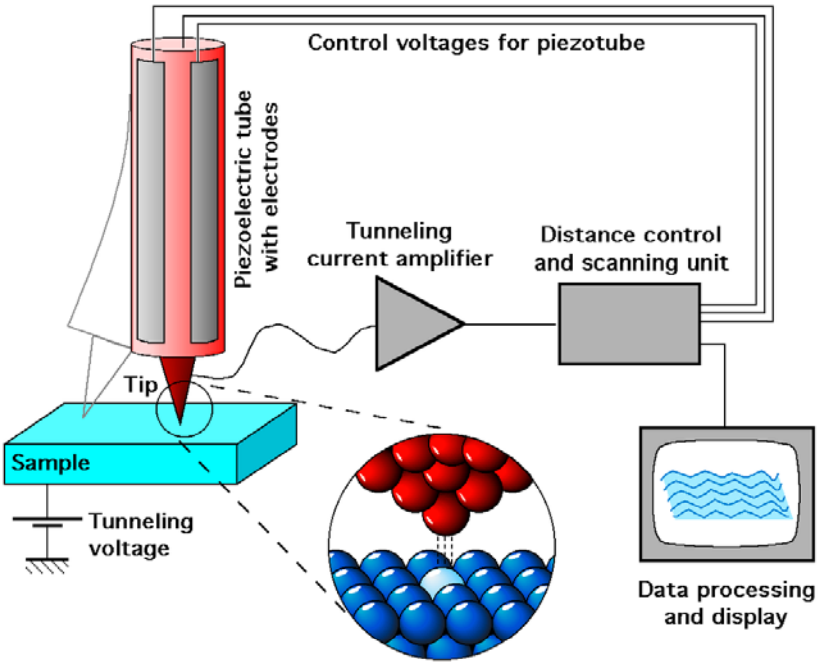
Gerd Binnig **Heinrich Rohrer**







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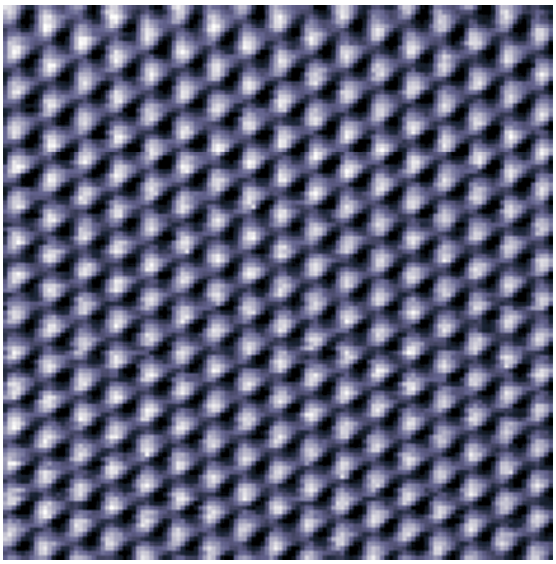
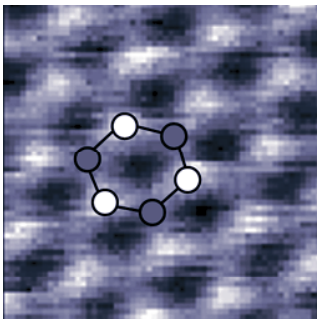
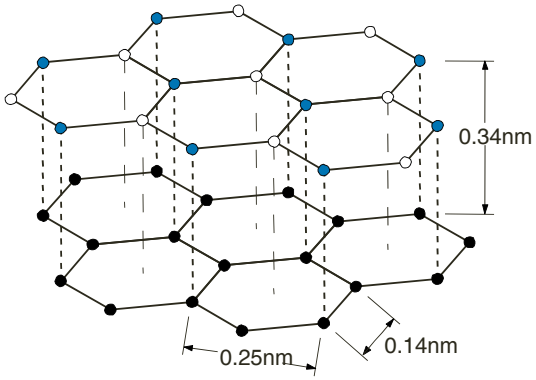


scan size: 4 nm

U=0.1V I=1nA





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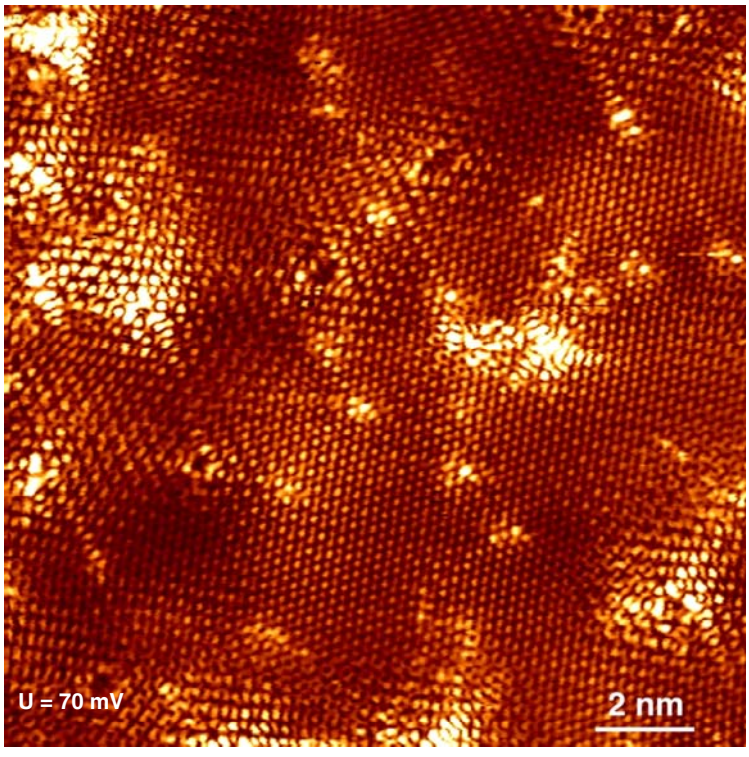

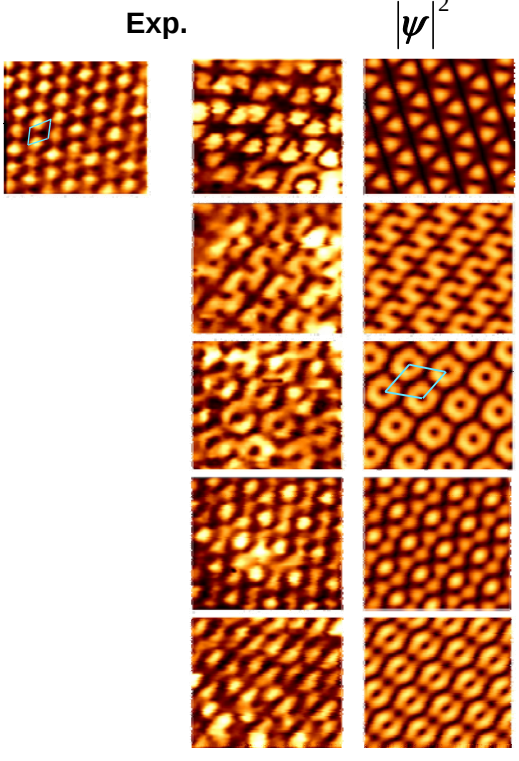

P. Ruffieux et al., PRB 71, 153403 (2005), PRL 84, 4910 (2000)

ist aber nicht alles…

Fullerene

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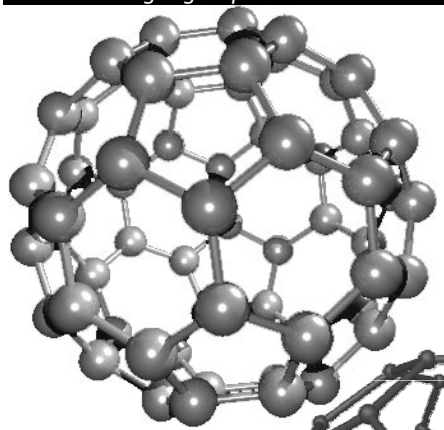
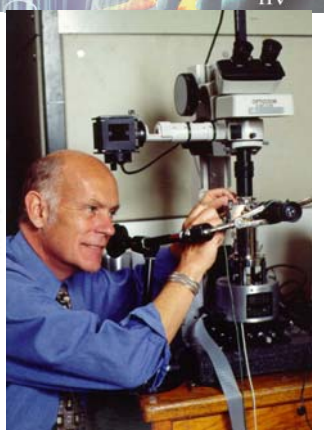
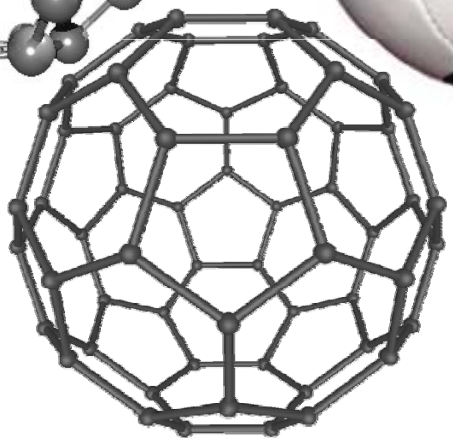
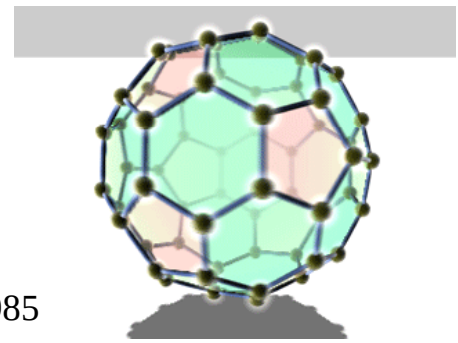






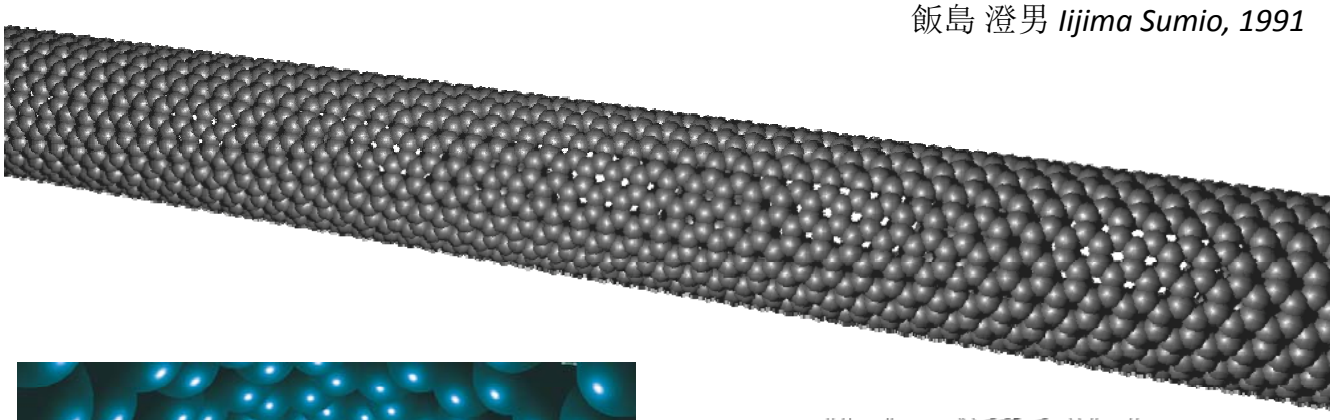
C_{60}

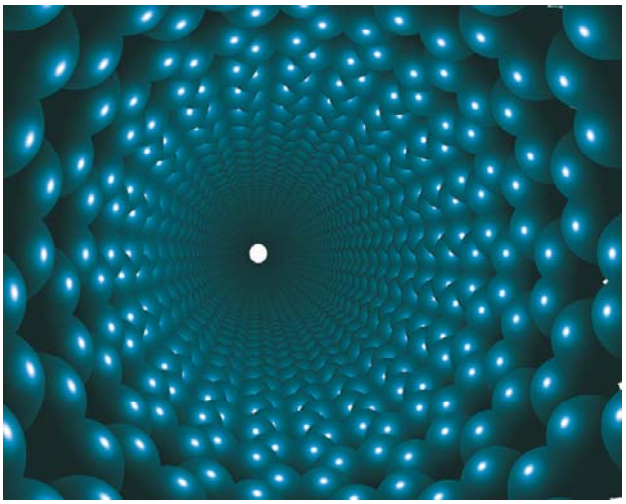


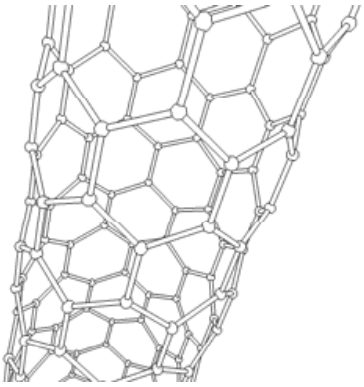
"The most symmetrical large molecule" discovered in 1985
Nobel prize in Chemistry 1996, Curl, Kroto, and Smalley

Carbon Nanotubes

飯島 澄男 *Iijima Sumio, 1991*

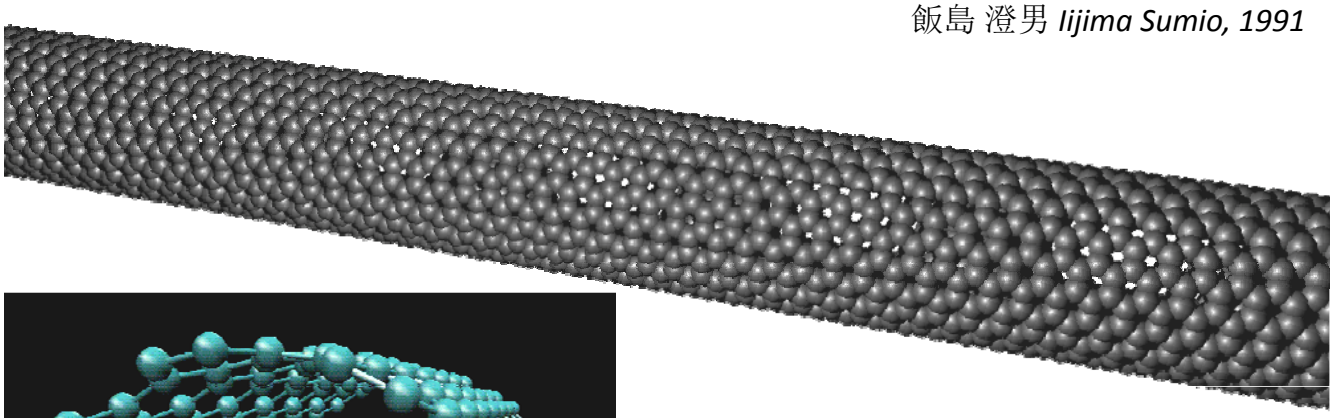


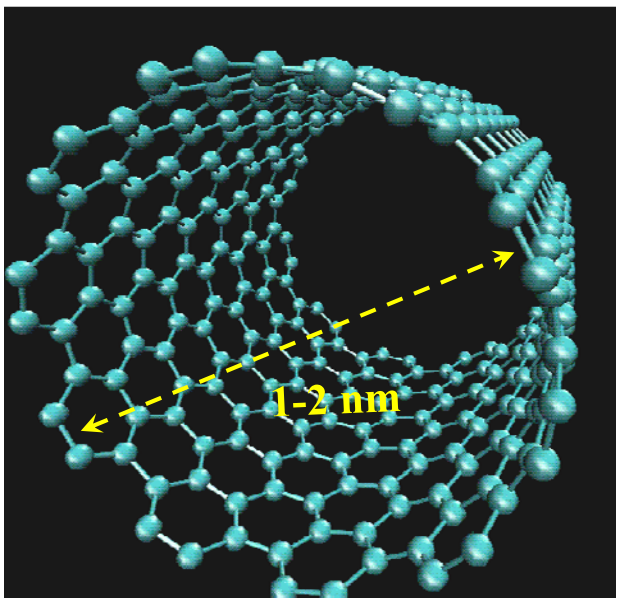


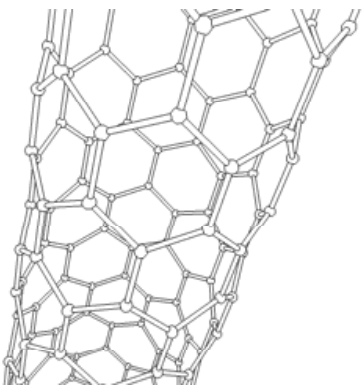


Carbon Nanotubes

飯島 澄男 *Iijima Sumio, 1991*

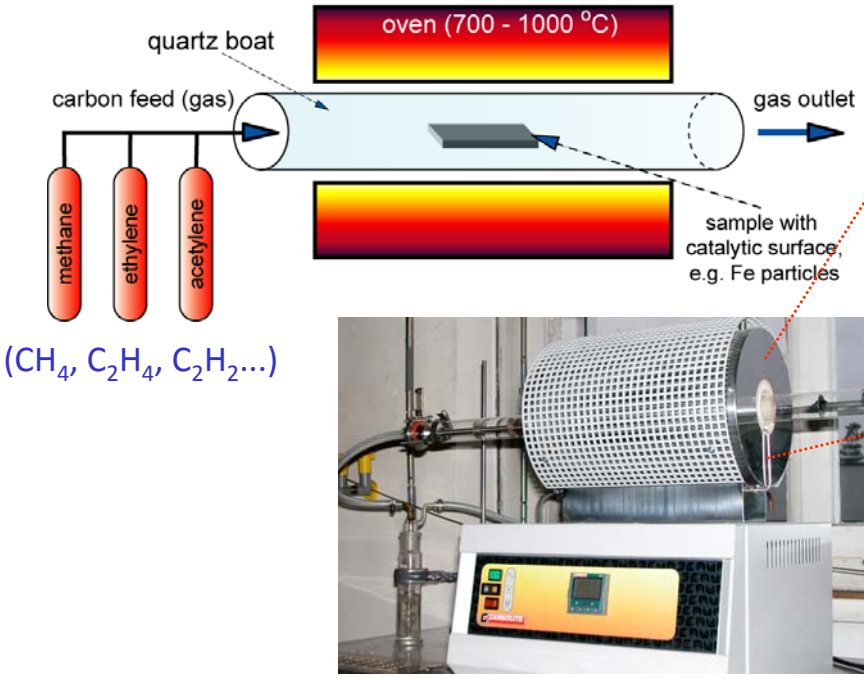






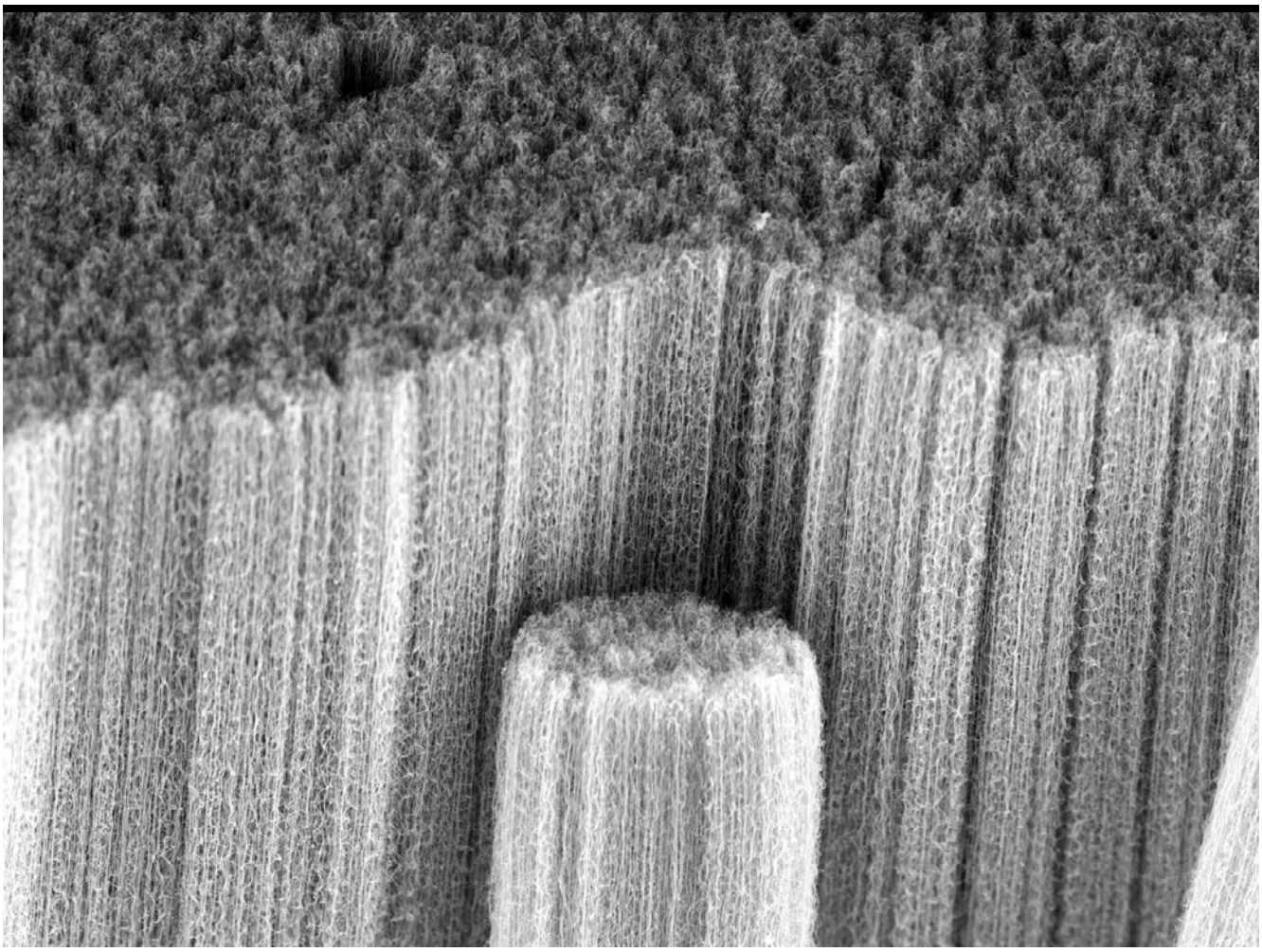
Herstellung: Chemical Vapor Deposition

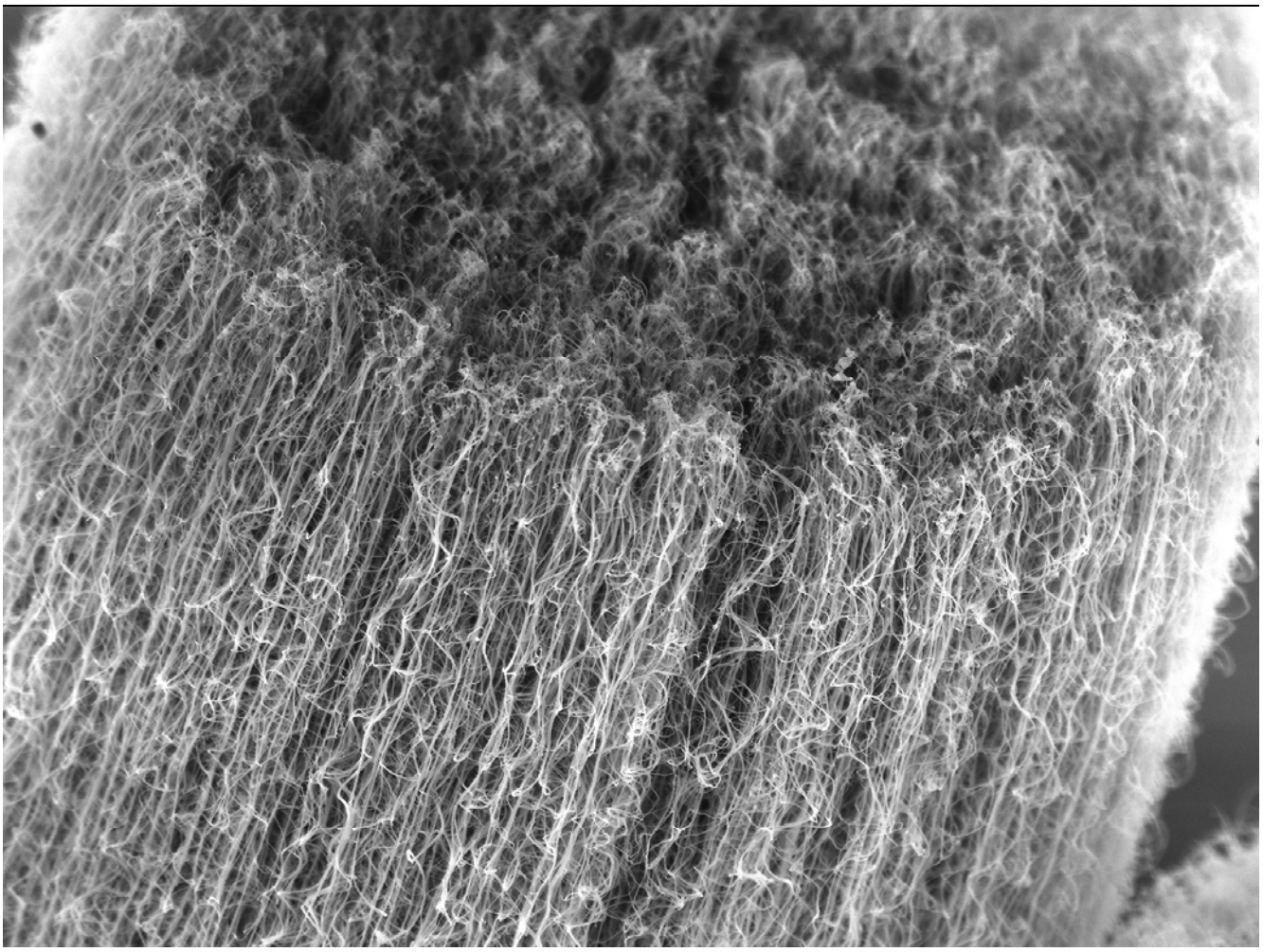
CVD

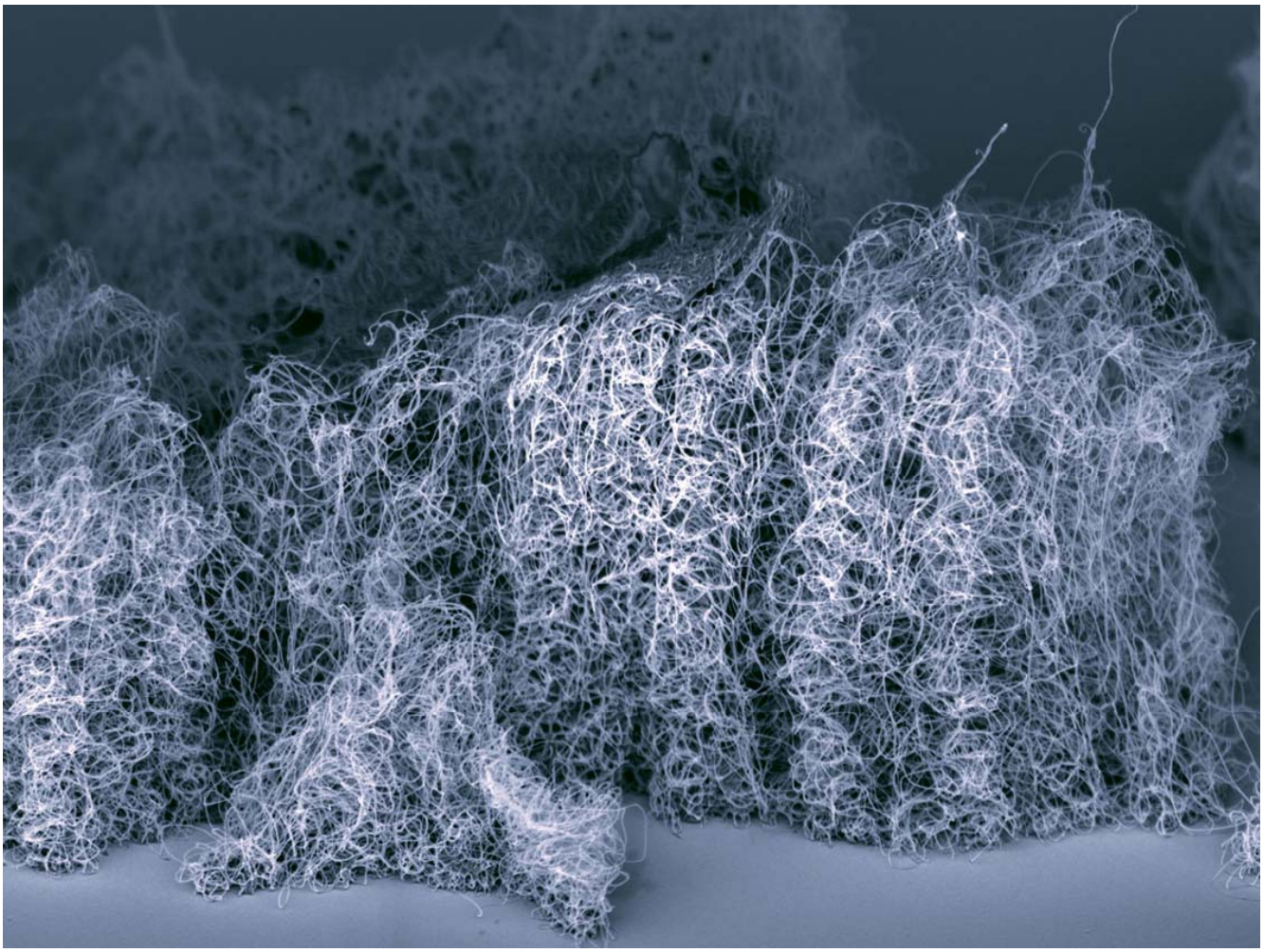


(CH_4, C_2H_4, C_2H_2...)

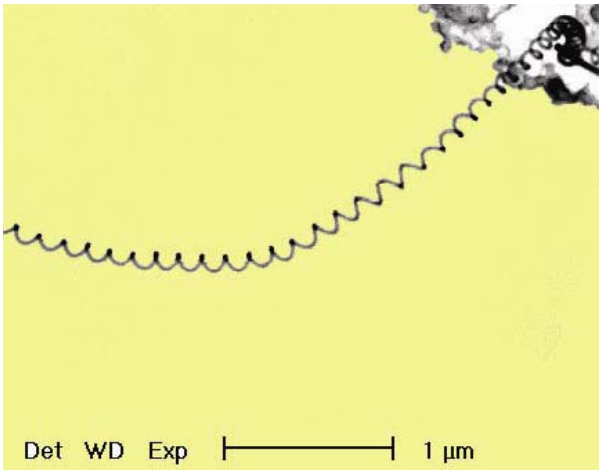
Carbon Nanotubes

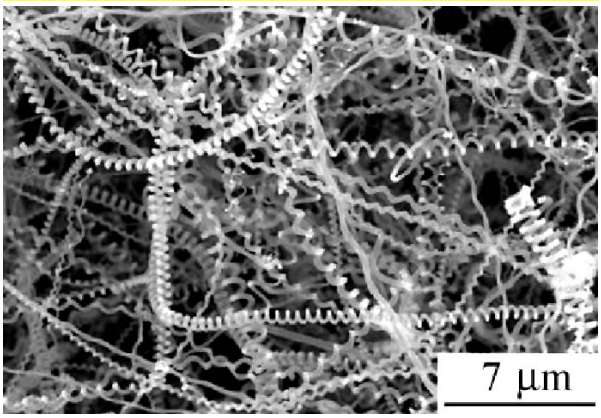


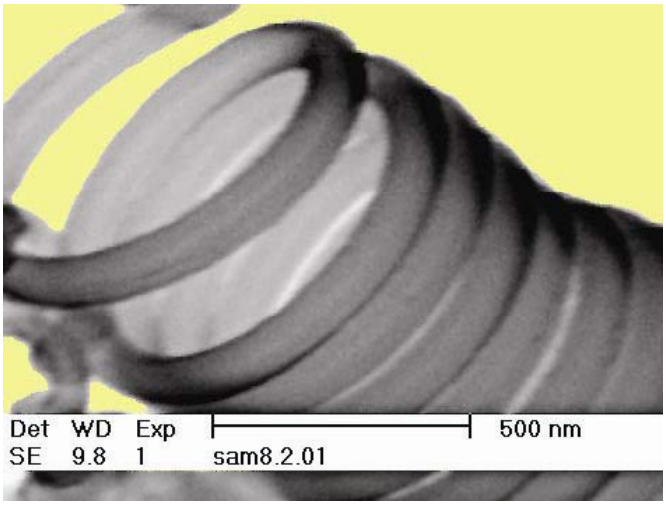




Herstellung von Carbon Nanotubes







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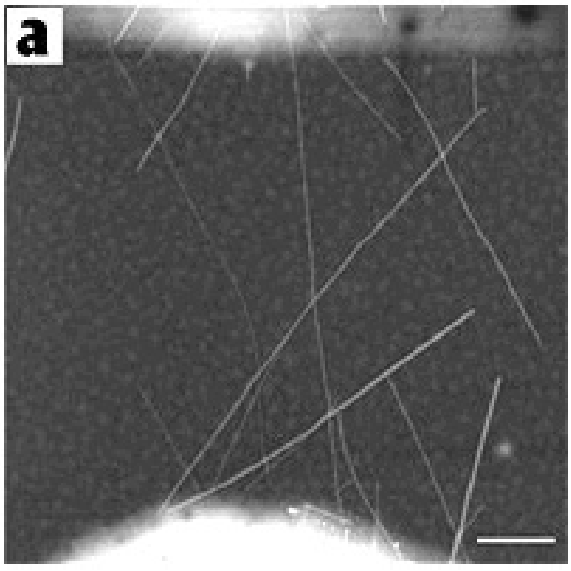
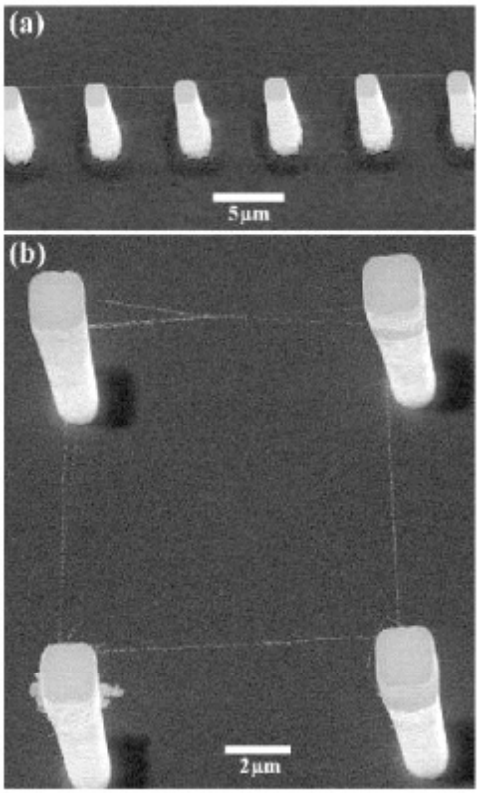


from the DaiLab @ Stanford



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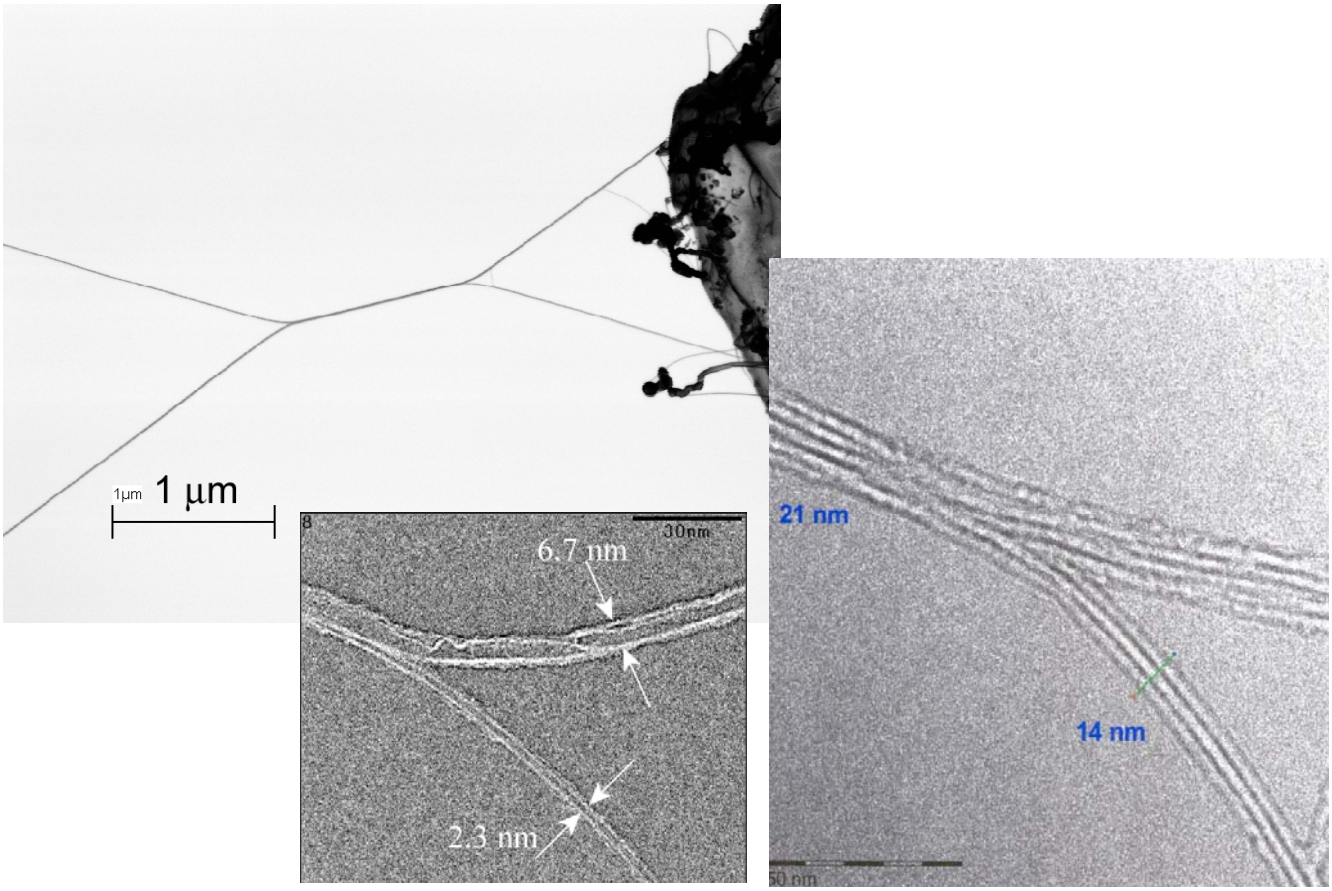
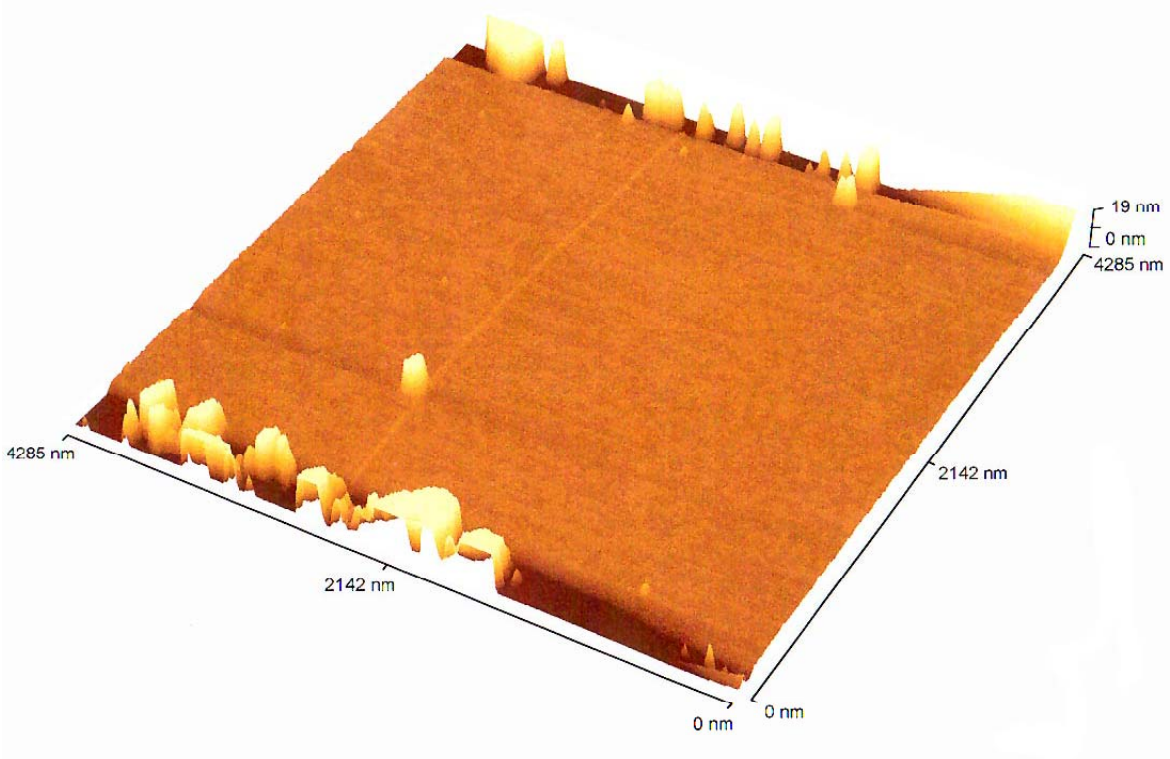
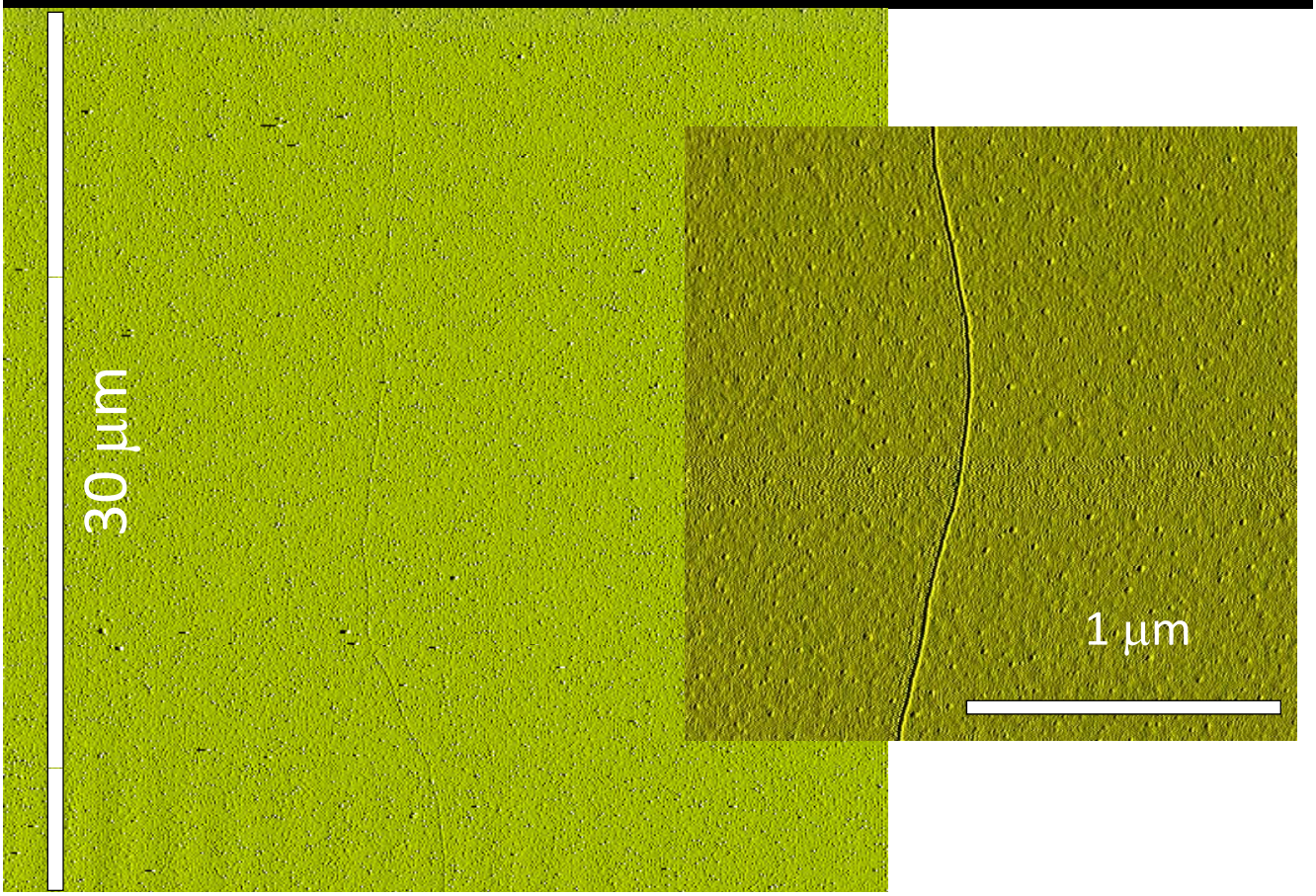


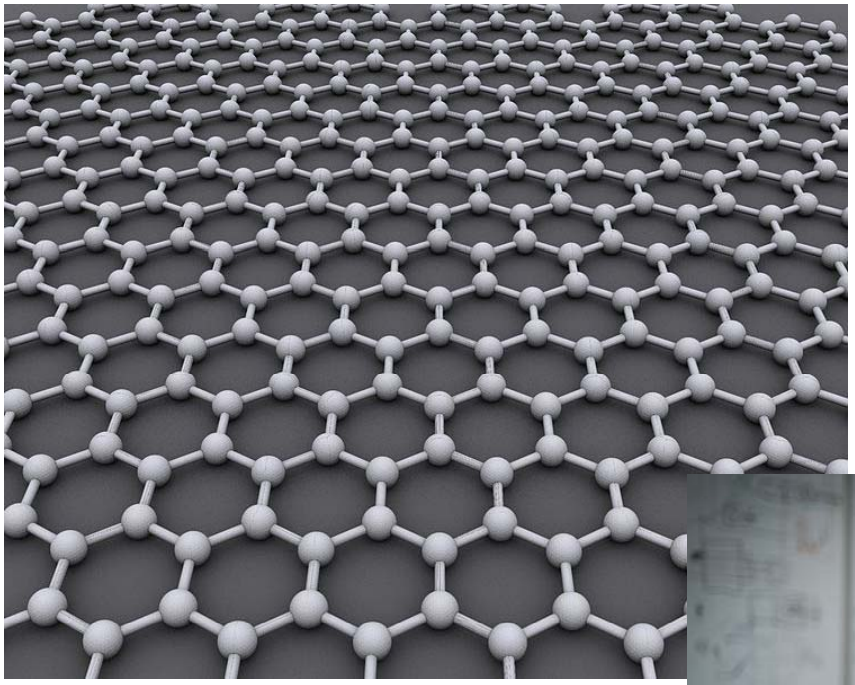
Herstellung von Carbon Nanotubes



Herstellung von Carbon Nanotubes

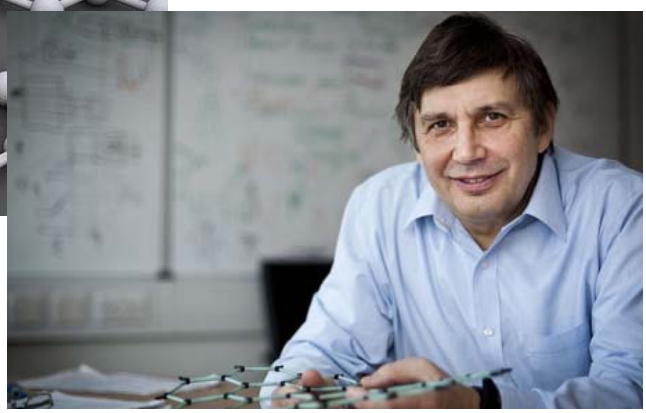


Graphene



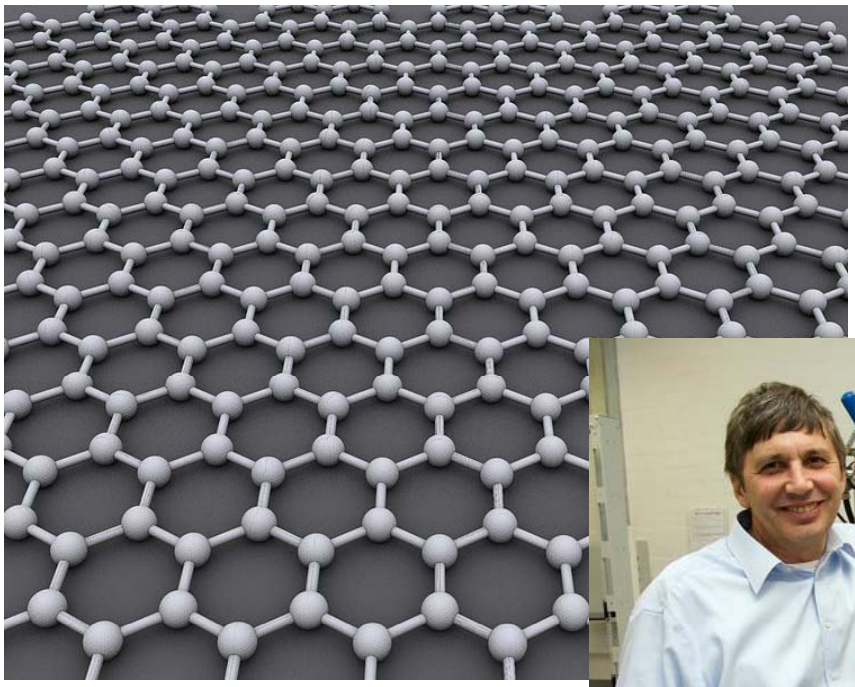
atomar dünn

nur eine Monoschicht



2004 entdeckt, 2010 Nobelpreis für Physik

Graphene



atomar dünn

nur eine Monoschicht

2004 entdeckt, 2010 Nobelpreis für Physik

Graphene

The Telegraph

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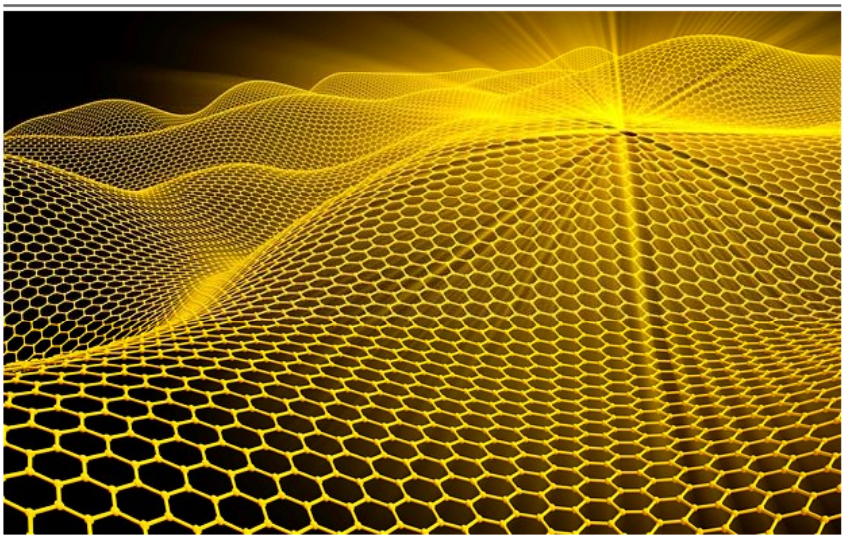
Graphene: A new miracle in the material world

Britain is investing £60m in developing graphene. But are our businesses already falling behind in the race to exploit it, asks Rebecca Clancy.



Graphene is a planar sheet of carbon atoms arranged in a hexagonal pattern. Stacked graphene sheets form graphite, used in

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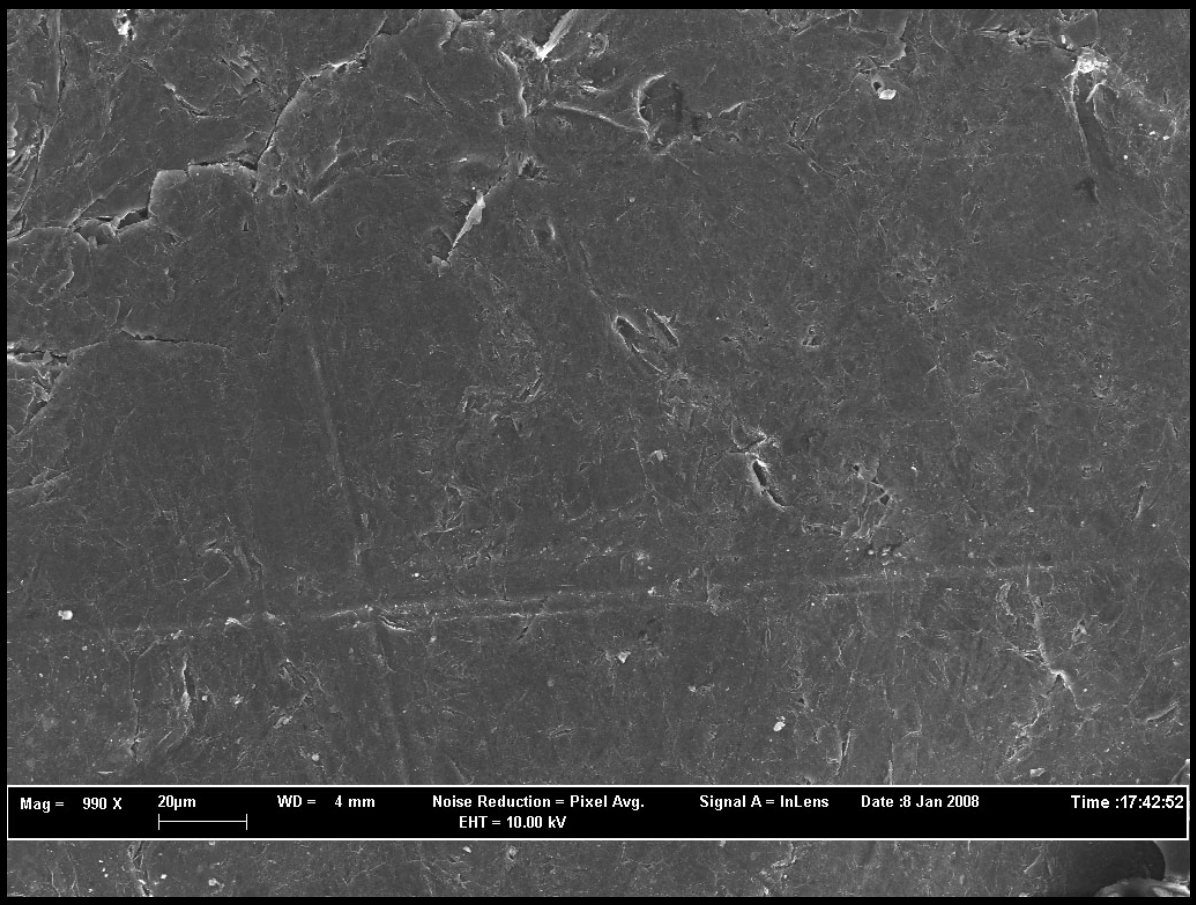
Graphite ➔ Graphene

natural graphite crystals

synthetic highly oriented graphite

im Elektronenmikroskop Graphite



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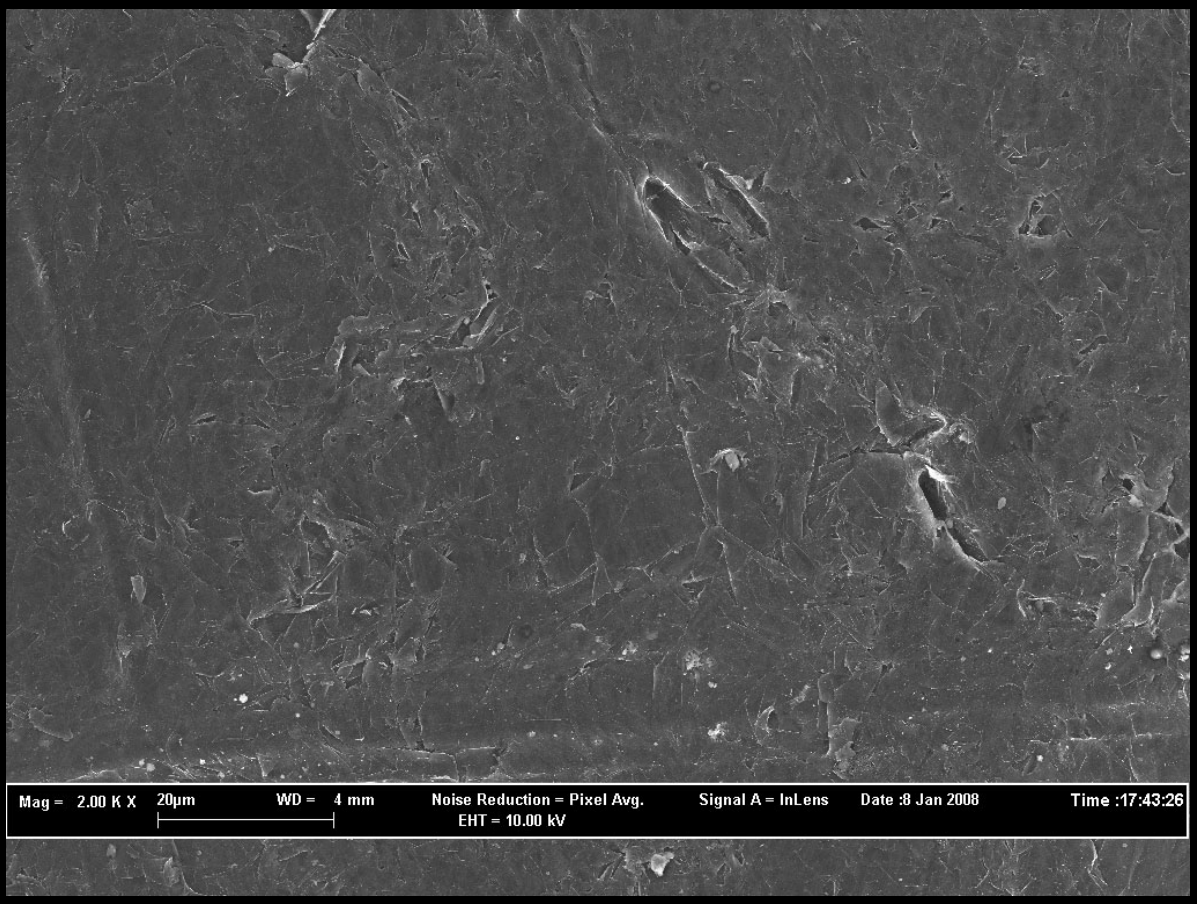

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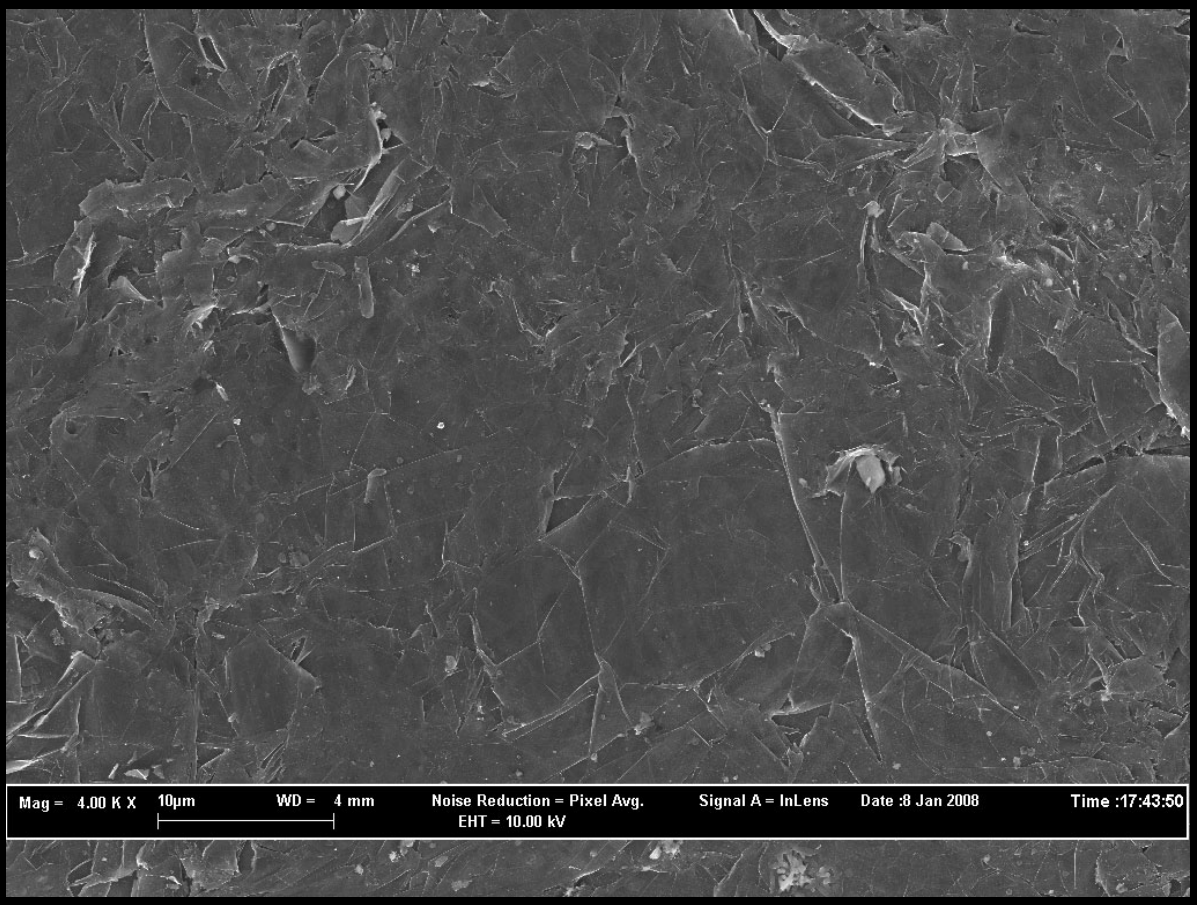

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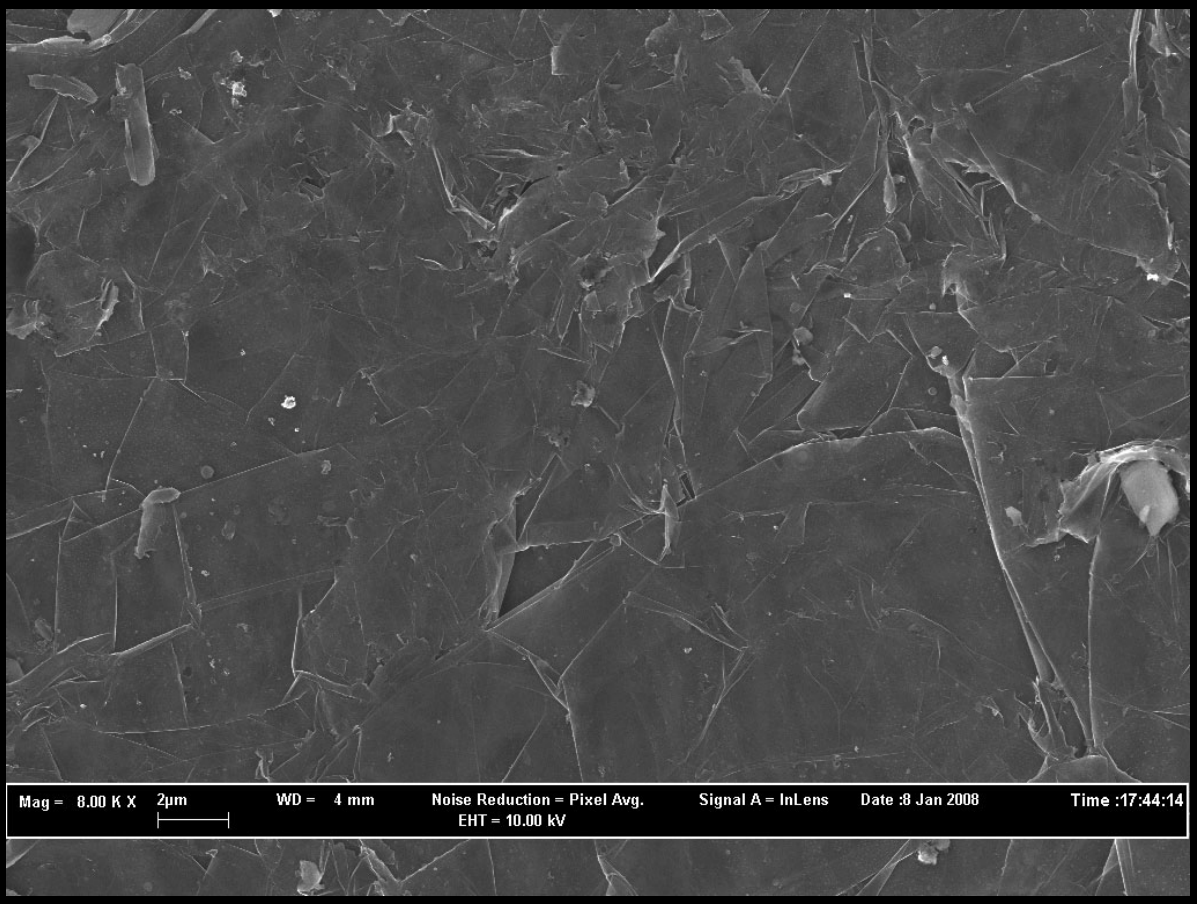

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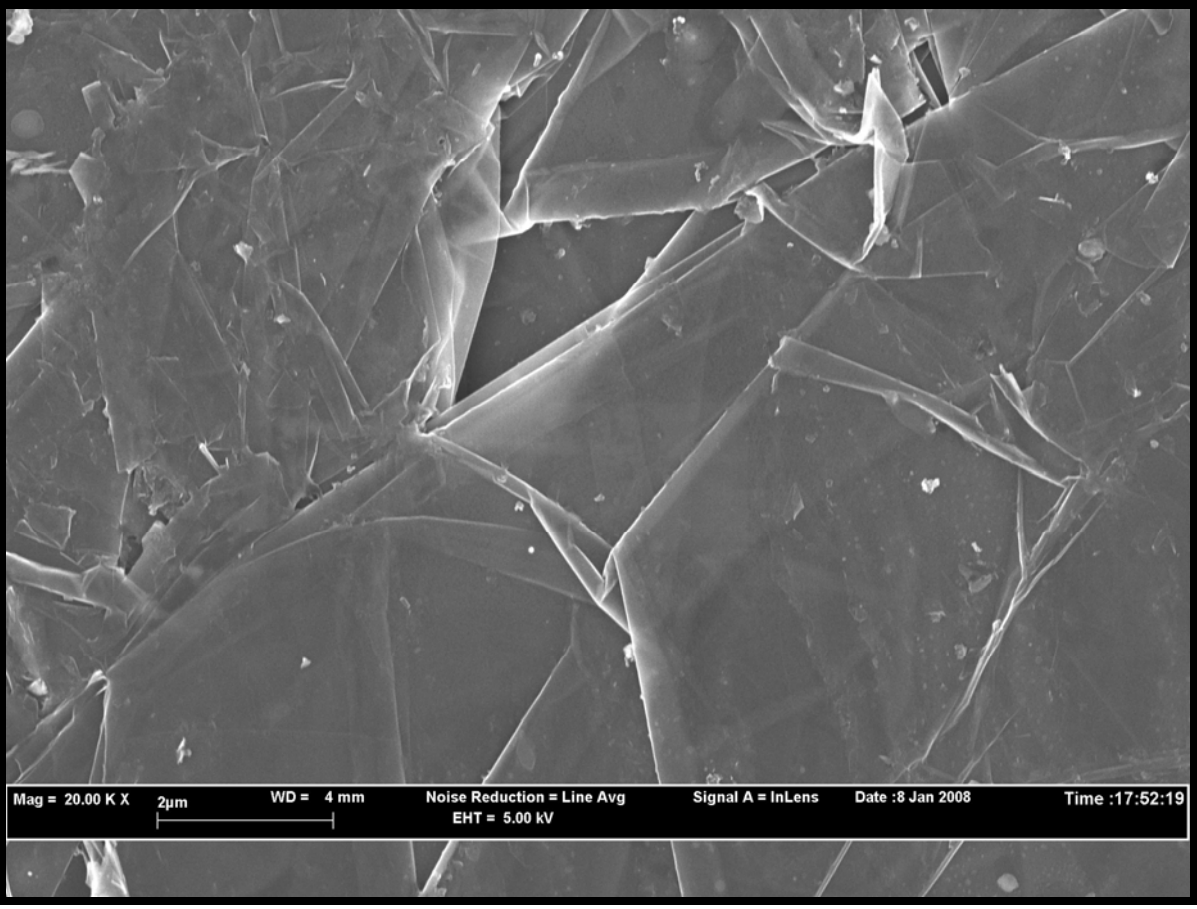

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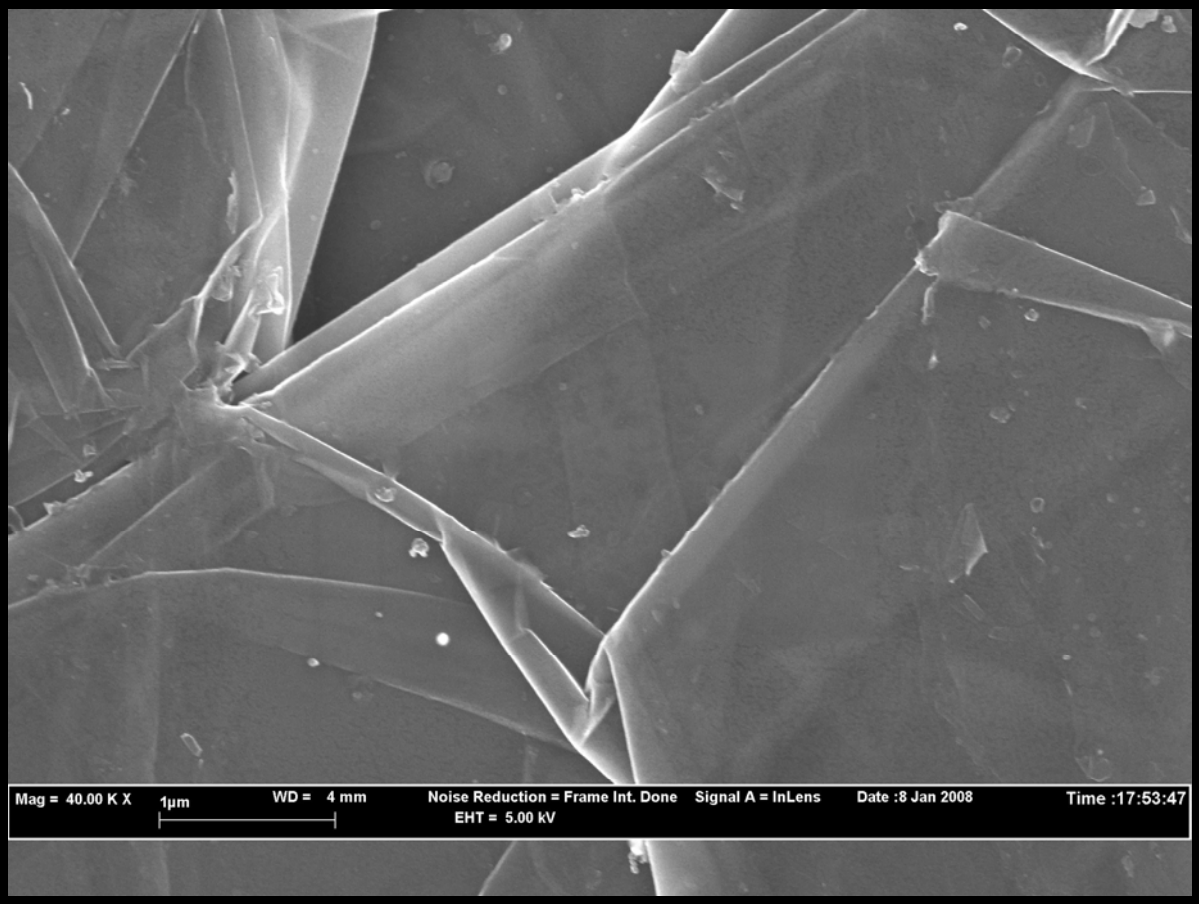

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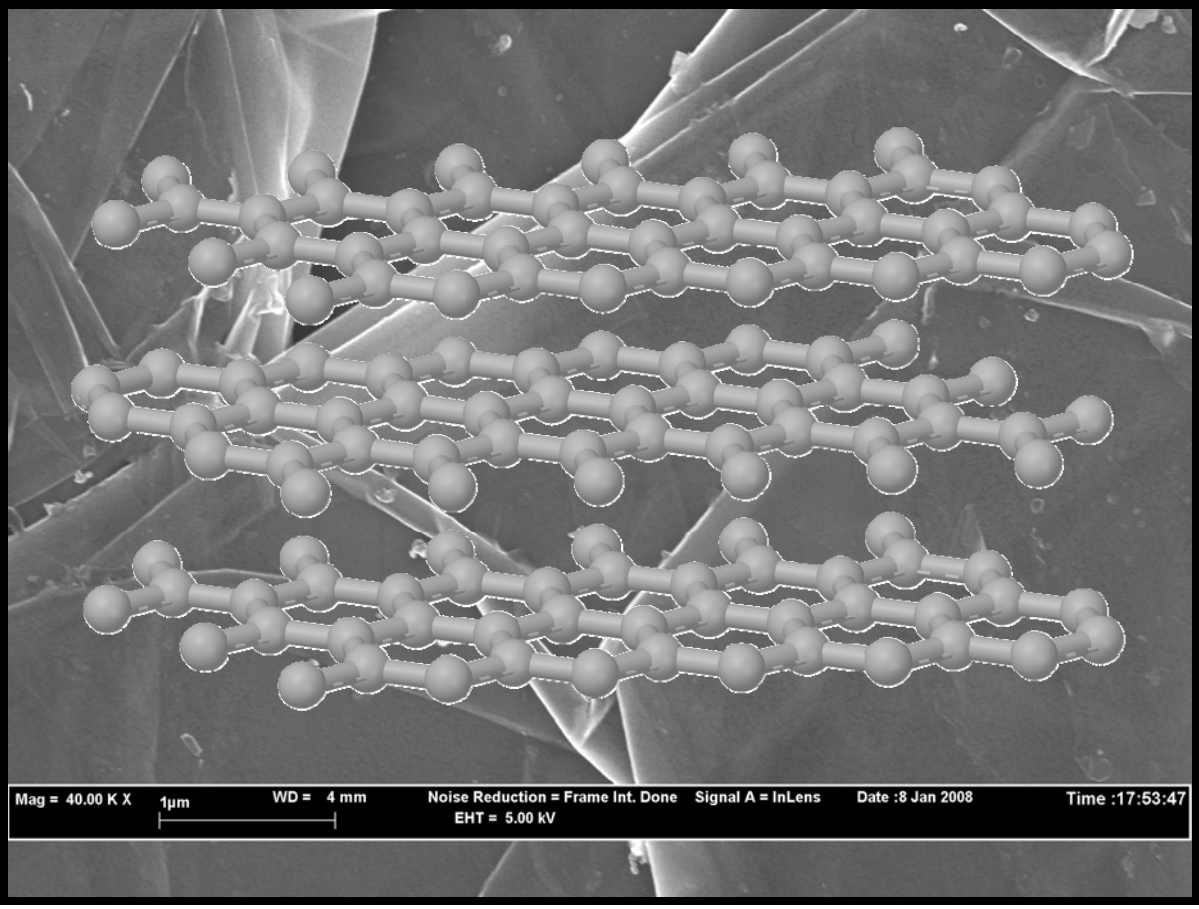
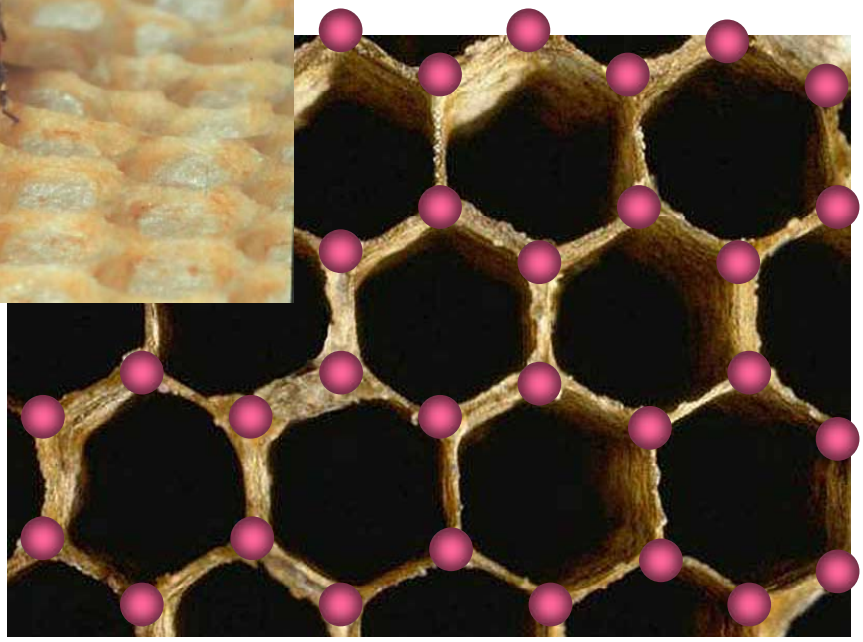
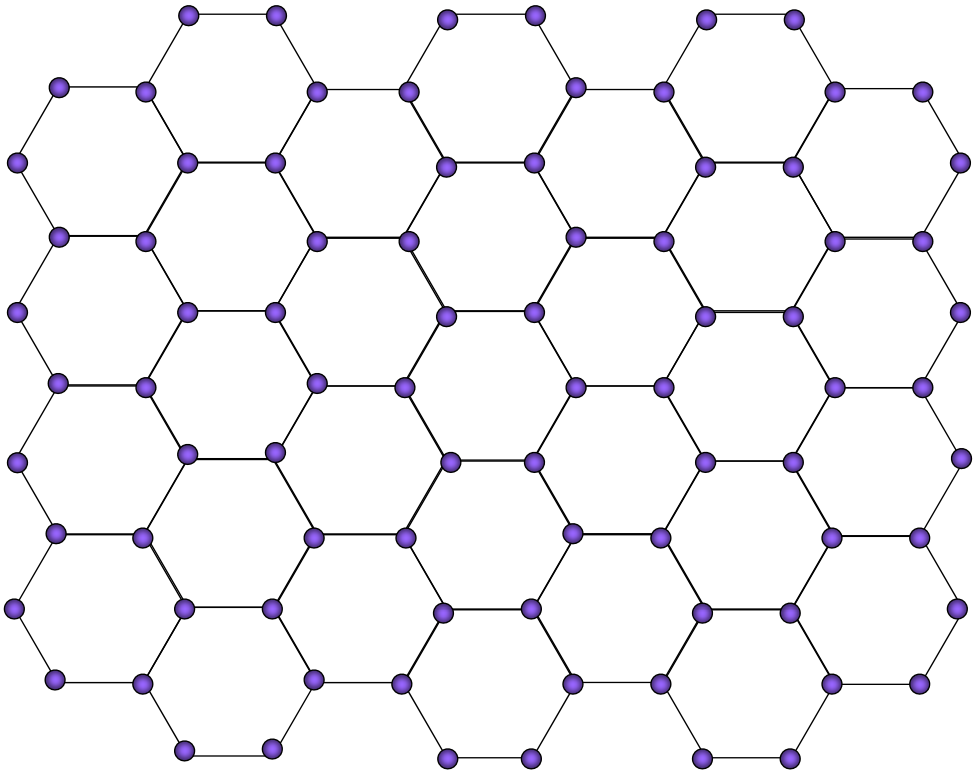


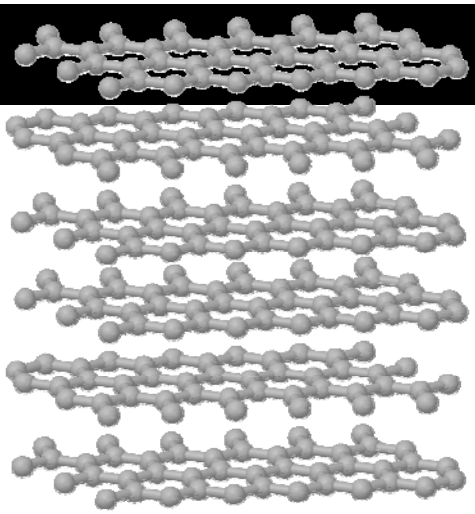
Graphene

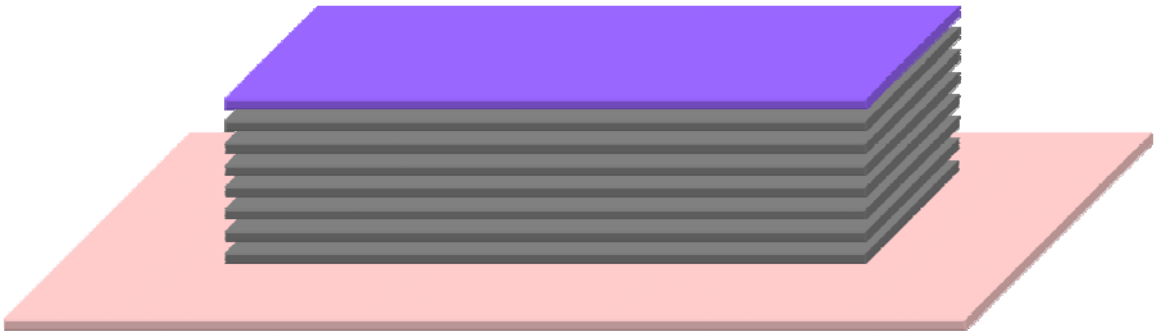


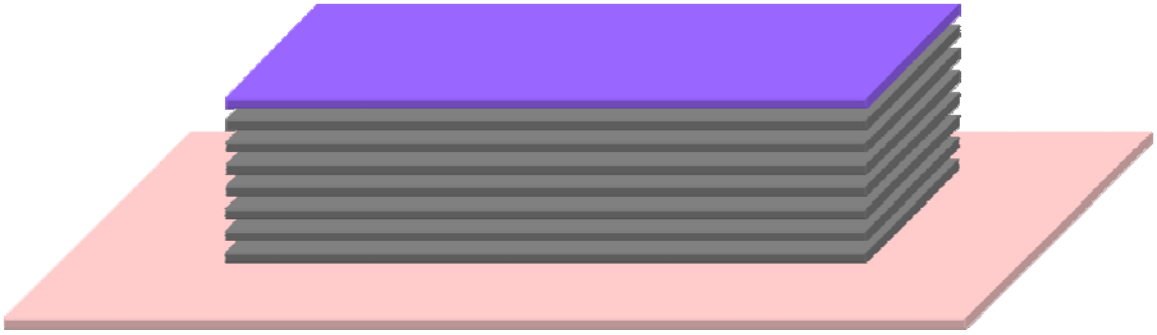
Graphene

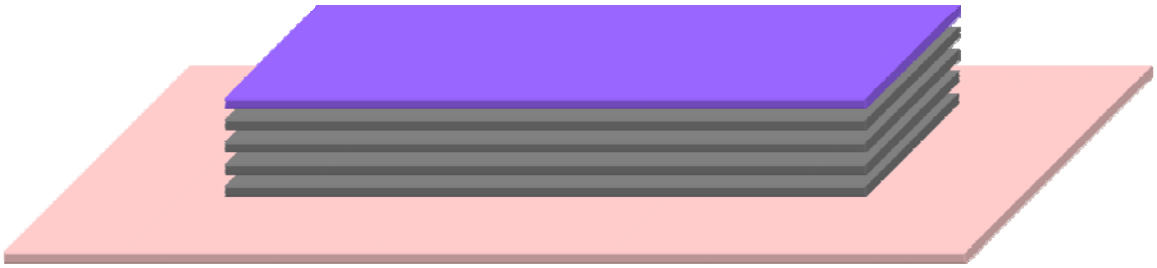


how to make it ?

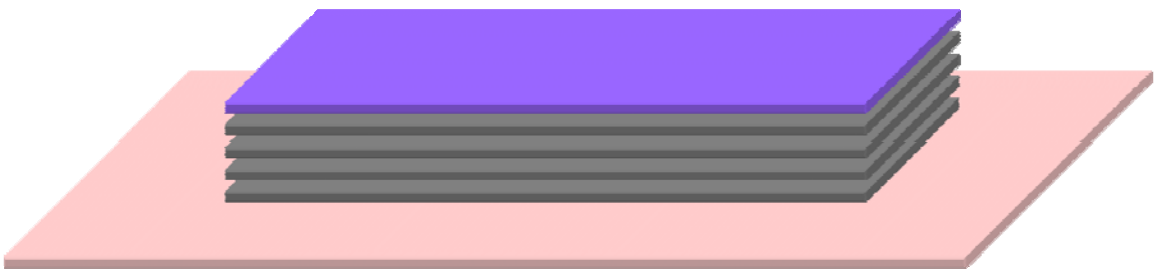




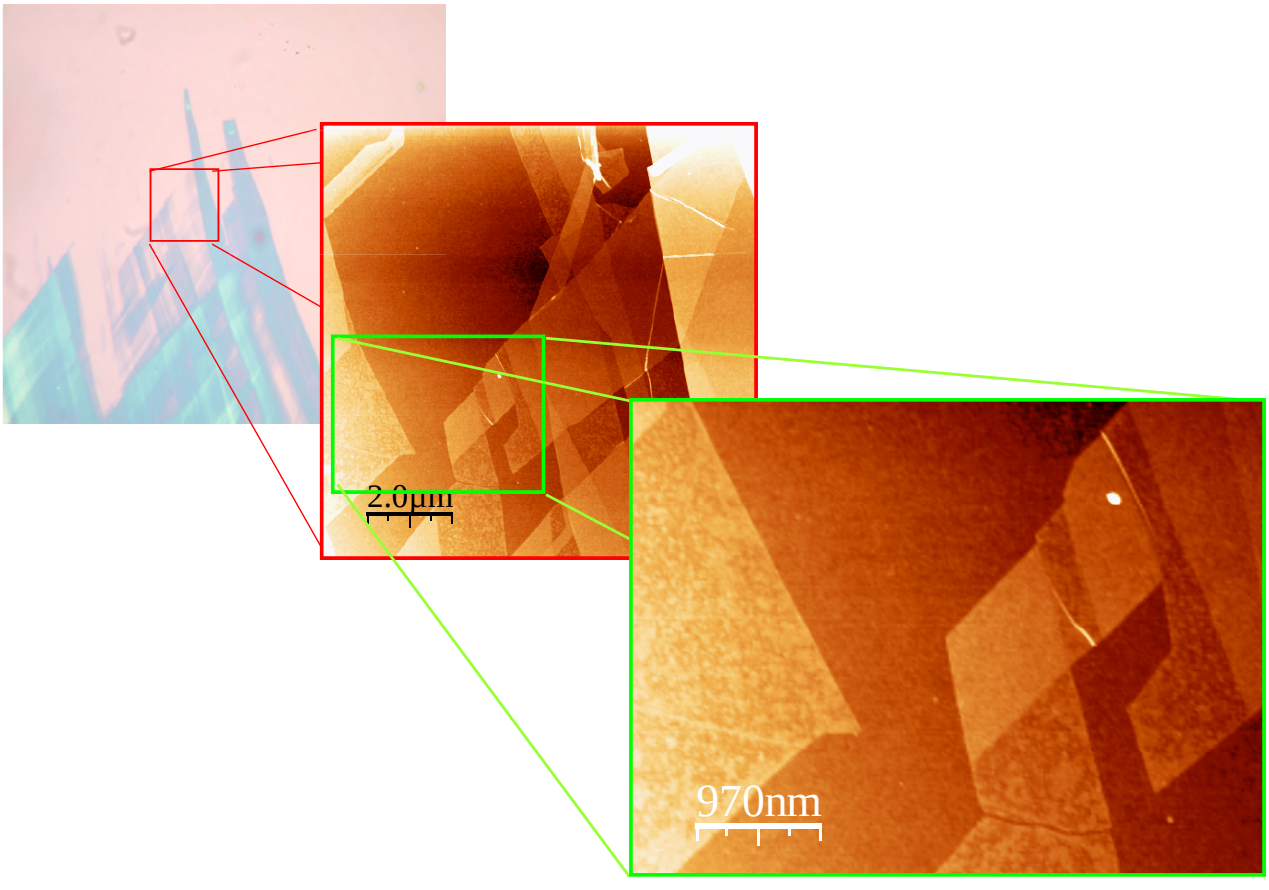




Soooo thin – we can hardly see it



Graphene

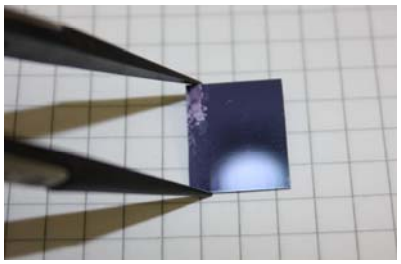


Graphene

Take some graphite:

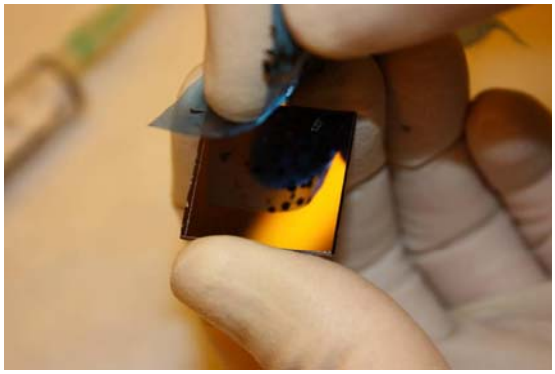
Sticky tape:

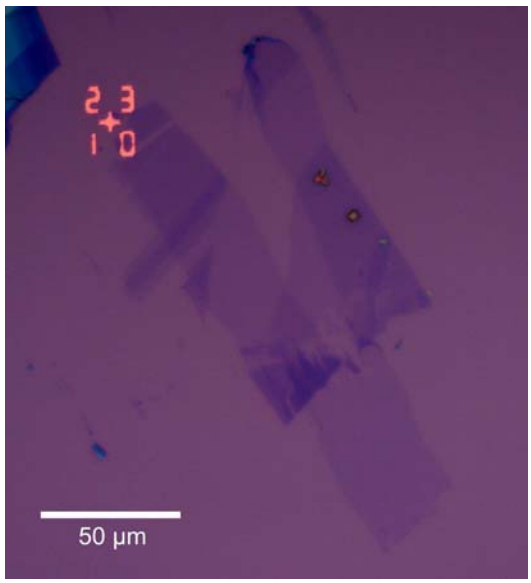
Silicon wafer:



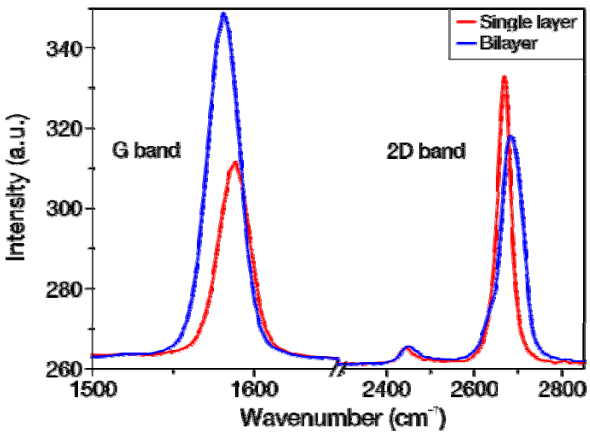
Cleave the graphite, press tape on wafer

Graphene characterization



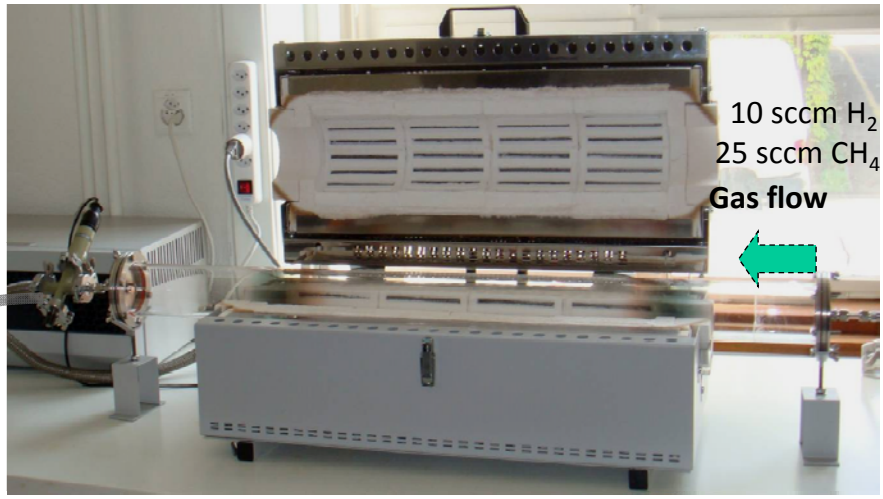


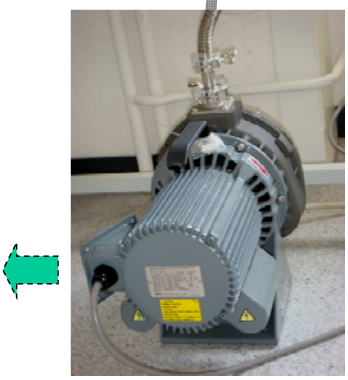
Optical microscope, graphene on Si substrate with 300 nm SiO_2



Raman spectra

CVD graphene (growth)



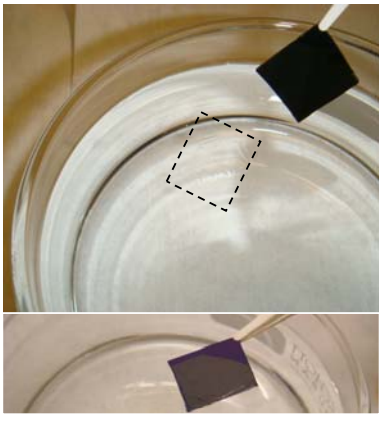


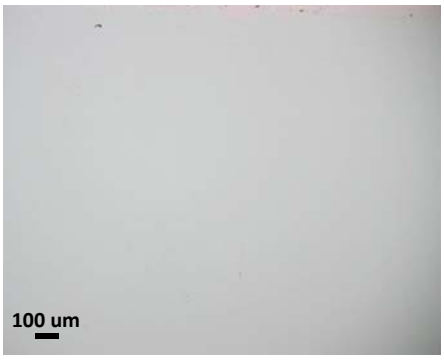
20 min @ 1000°C
LPCVD (base pressure: 4Pa)

CVD graphene (transfer)

Cu etching

The "fishing"

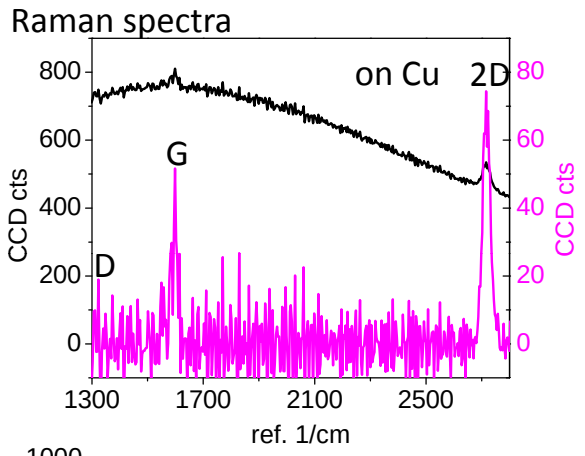


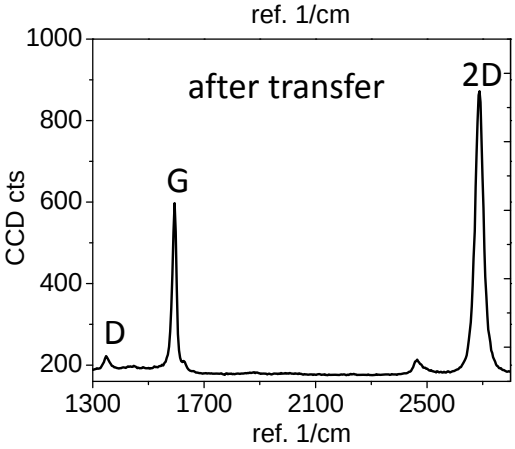


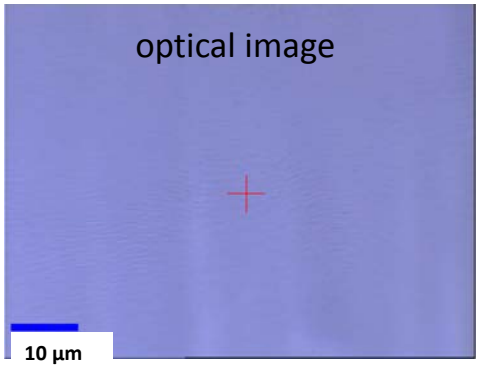
large area,
high quality
monolayer graphene

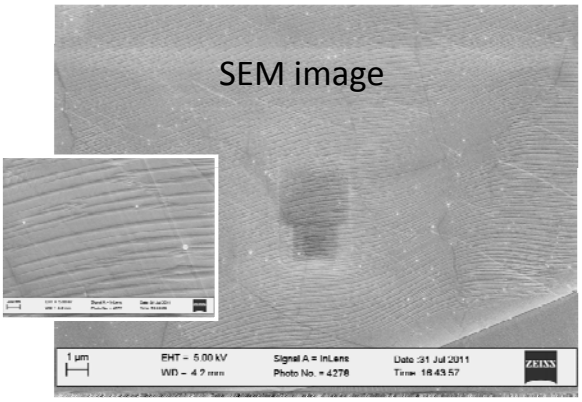
Li et al. Nano Letters **2009**, *9*, 4359

CVD graphene (characterization)

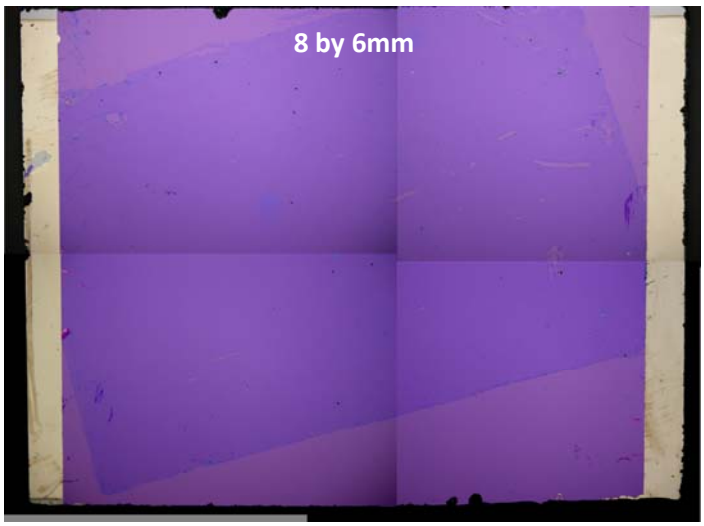


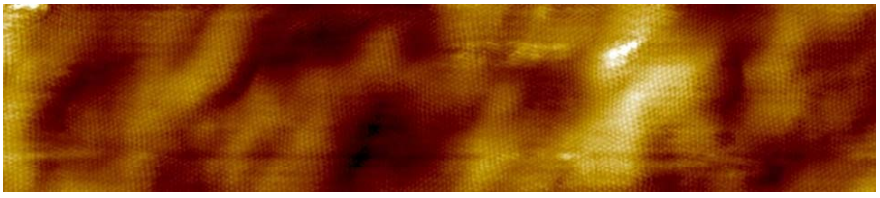




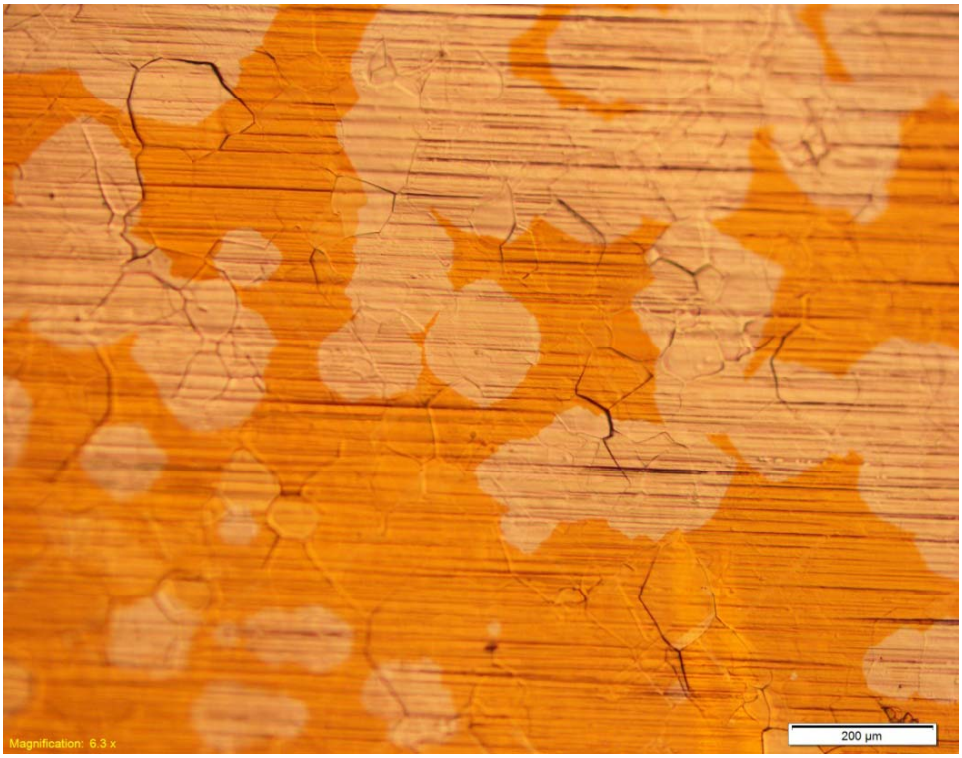


CVD graphene (characterization)

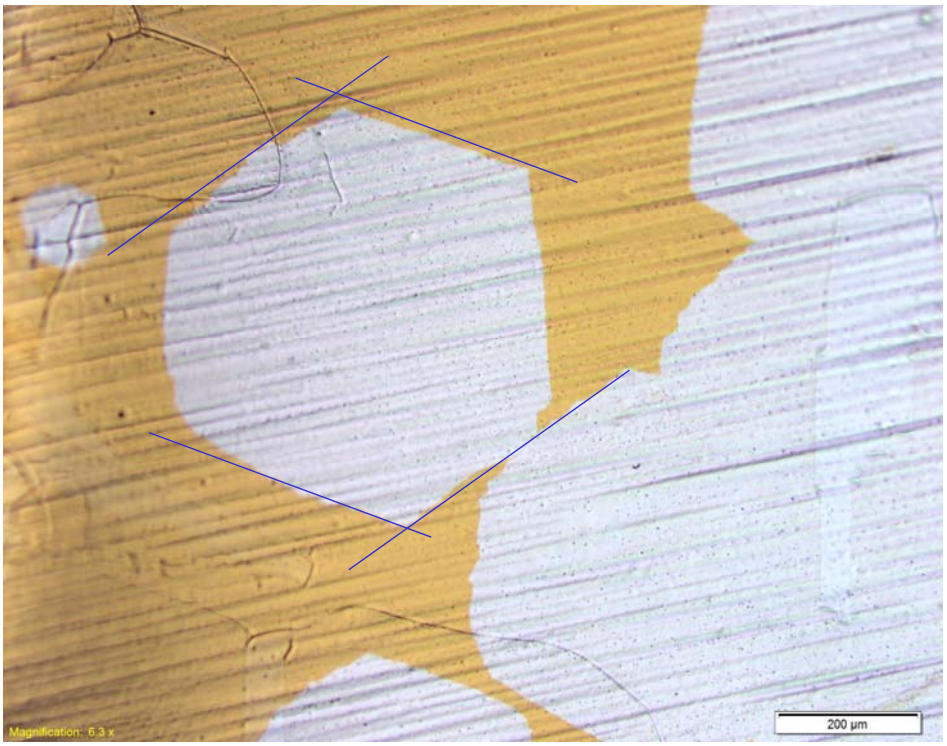




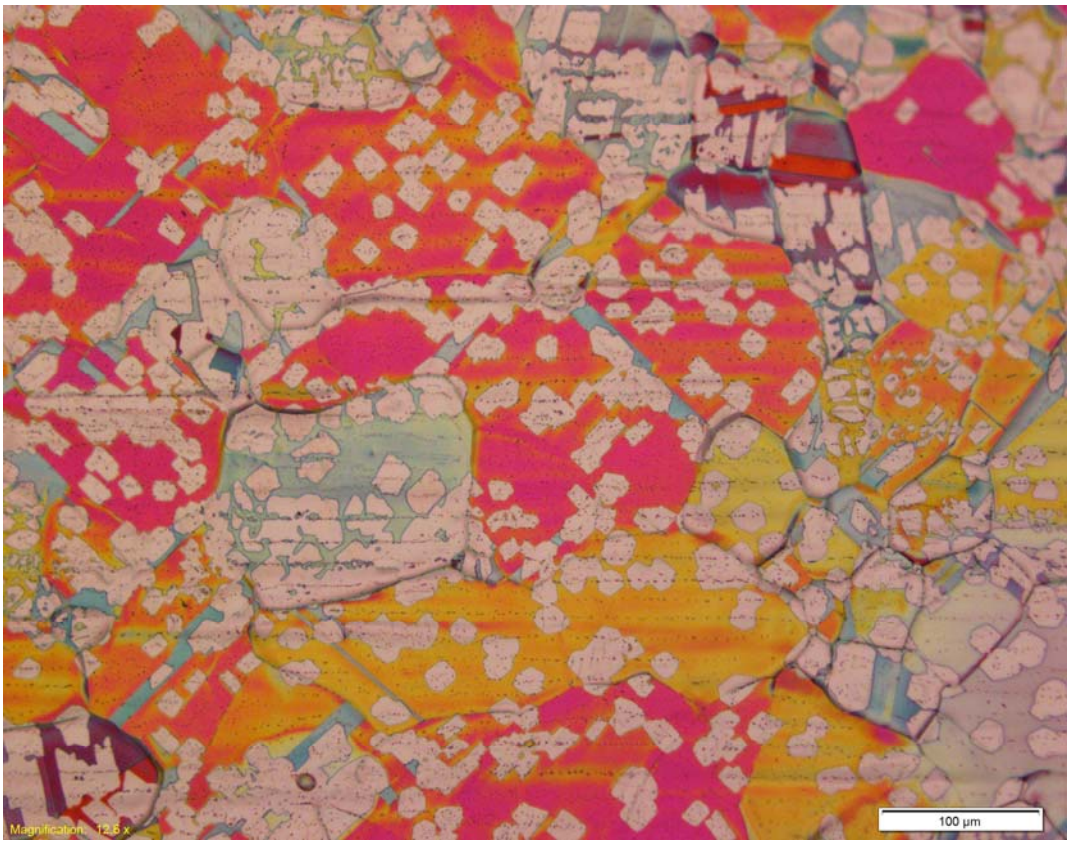
Graphen (Einkristalle)



Graphen (Einkristalle)



Graphen (Einkristalle)



Graphene from SiC

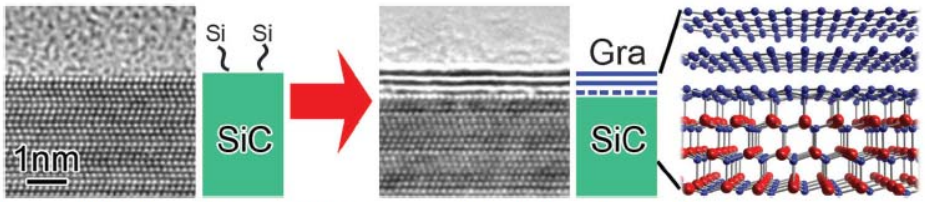
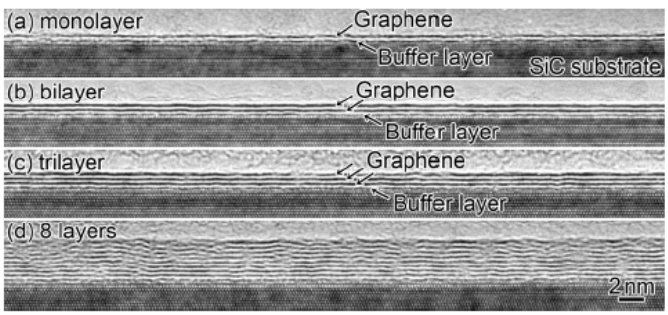
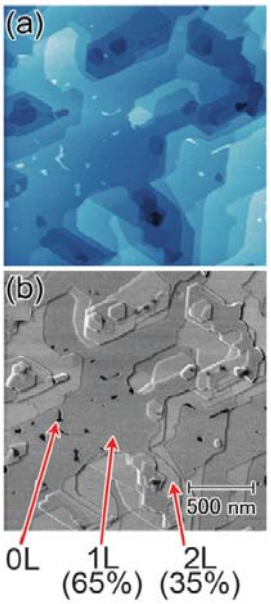


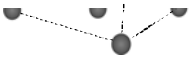
Fig. 2 Basics of graphene growth by thermal decomposition of SiC, together with the structural model of bilayer graphene on SiC. Shown as the blue broken line is the buffer layer.

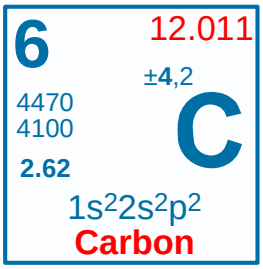


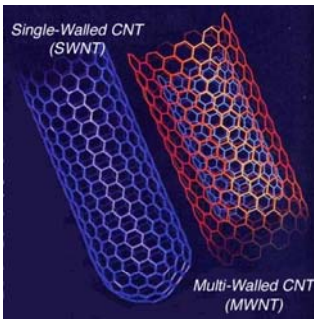


Kohlenstoff -- neue Formen

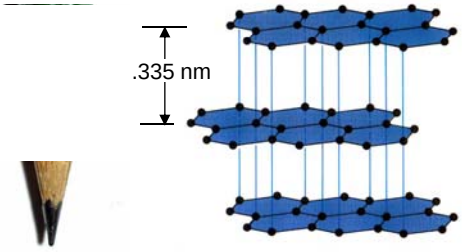
Diamant (sp^3 Carbon):
- *das härteste Material*
- *sehr guter Isolator, trotzdem aber exzellenter Wärmeleiter*







Nanotubes:
metallisch oder halbleitend
Durchmesser: 0.5 - 50 nm



Graphit (sp^2 Carbon):
- lässt sich leicht abtragen (Bleistift)
- recht guter elektrischer Leiter

ullerene (C_{60}):
Durchmesser = 0.7 nm