

# Measuring the Nanoworld

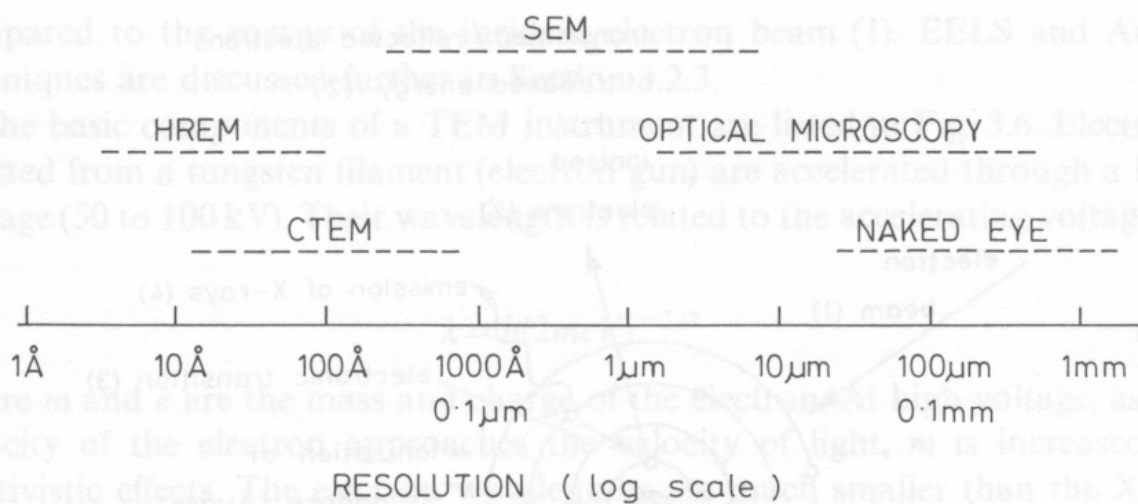
1. Electron Microscopy
2. Scanning Microscopies
3. Spectroscopies
4. Magnetic Measurements
5. Electric Measurements

30.10.2007

Nanochemistry UIO

1

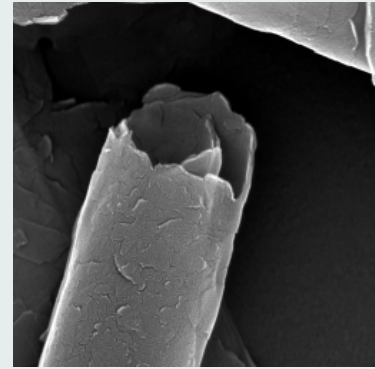
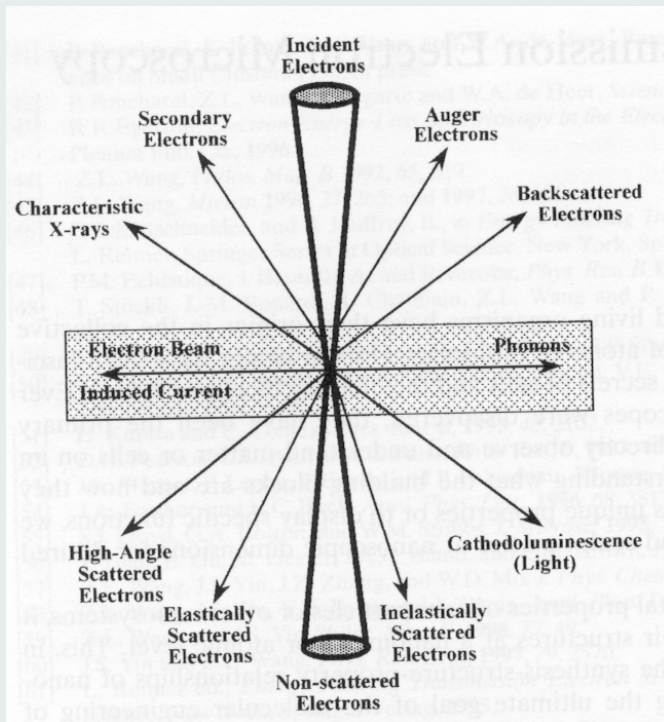
## Microscopy



Scanning  
surface methods

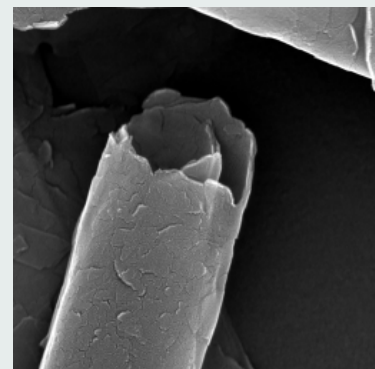
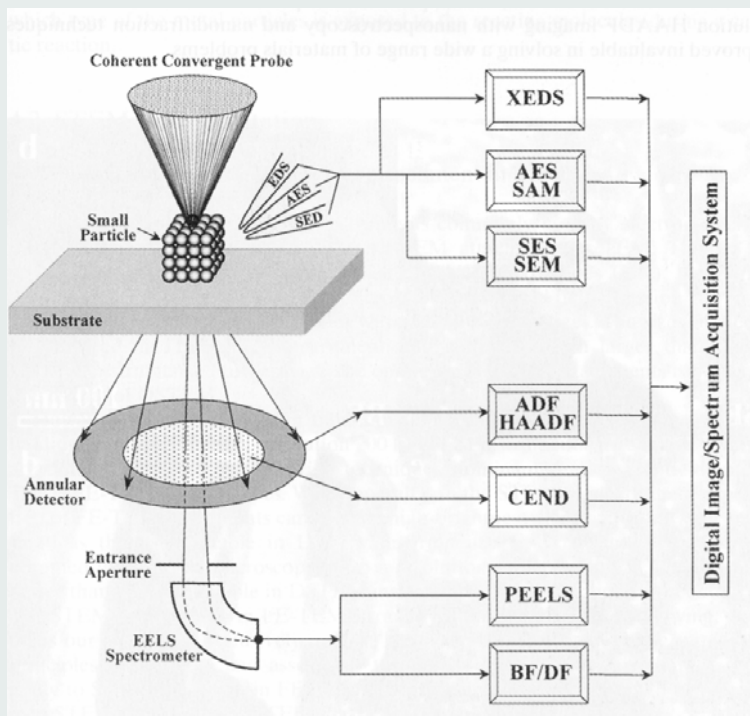
Nanochemistry UIO

# Scanning Electron Microscopy



Nanochemistry UIO

# Scanning Electron Microscopy - SEM



surface  
 analysis : 1  $\mu$  m

Nanochemistry UIO

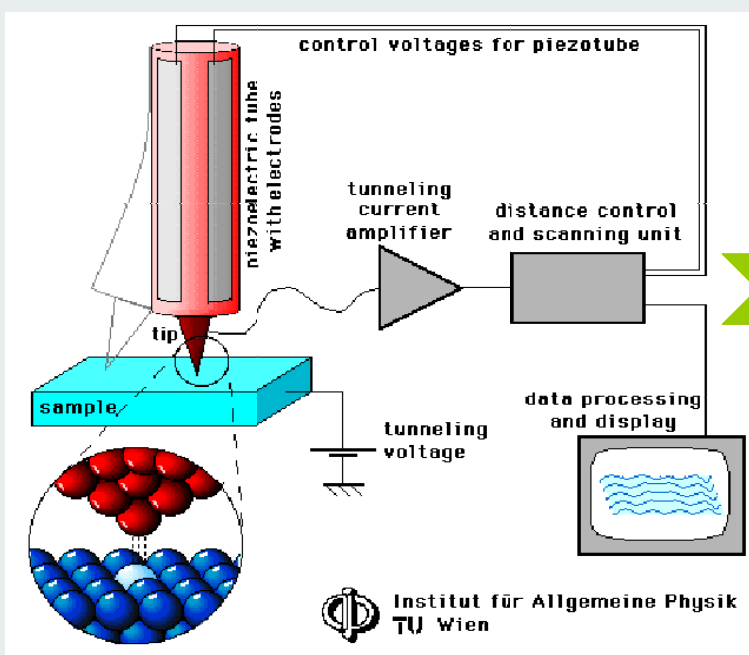
# Scanning Probe Microscopies

1. Scanning tunneling Microscopy - STM
2. Atomic Force Microscopy - AFM
3. Magnetic Force Microscopy - MFM
4. Chemical Force Microscopies - CFM

Nanochemistry UIO

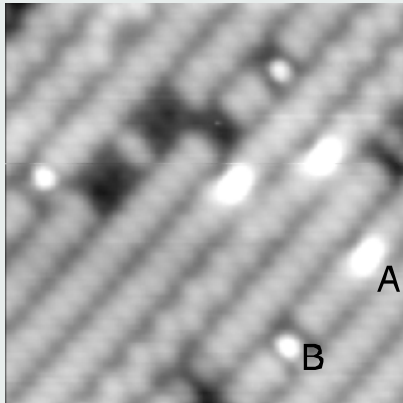
## Operation of an STM<sup>1,2</sup>

- [1] C. Julian Chen, *Introduction to Scanning Tunnelling Microscopy*, Oxford (1993)  
[2] G.A.D. Briggs and A. J. Fisher, *Surf. Sci. Rep.* **33**, 1 (1999)

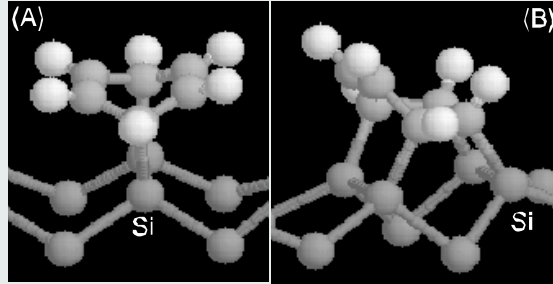


Nanochemistry UIO

# Example 1: benzene on Si(001)



STM image:  $U = -1.5$  V,  $I = 50$  pA



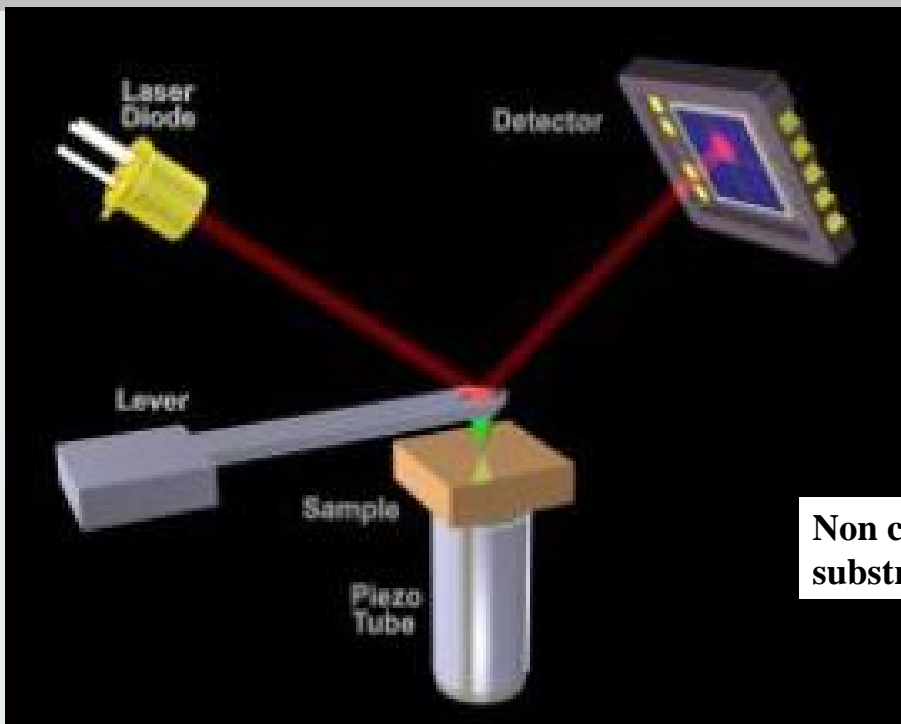
Single dimer bond

Tight bridge bond

Two binding sites  
with interconversion  
on lab timescales  
(Wolkow *et al.*)

Nanochemistry UIO

# AFM Technique

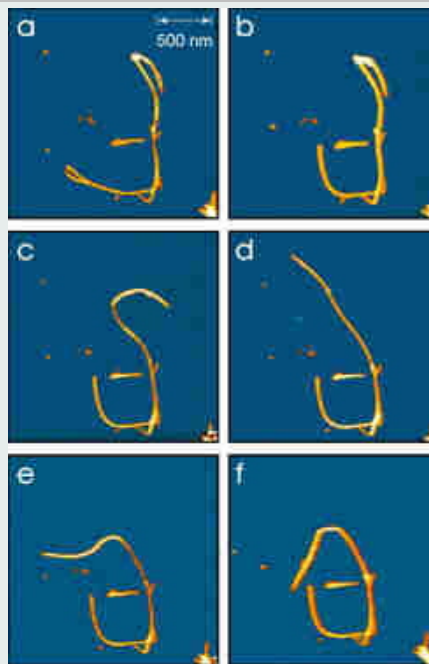


Non conducting  
substrates

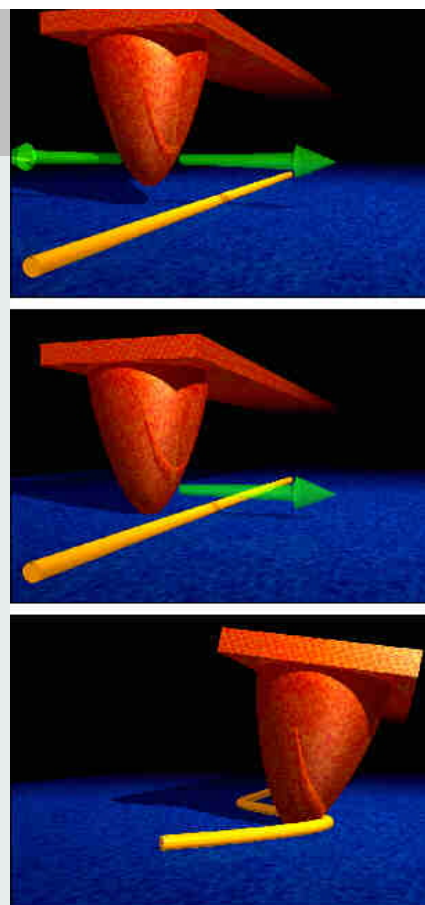
Nanochemistry UIO



# Manipulation of Nano Objects

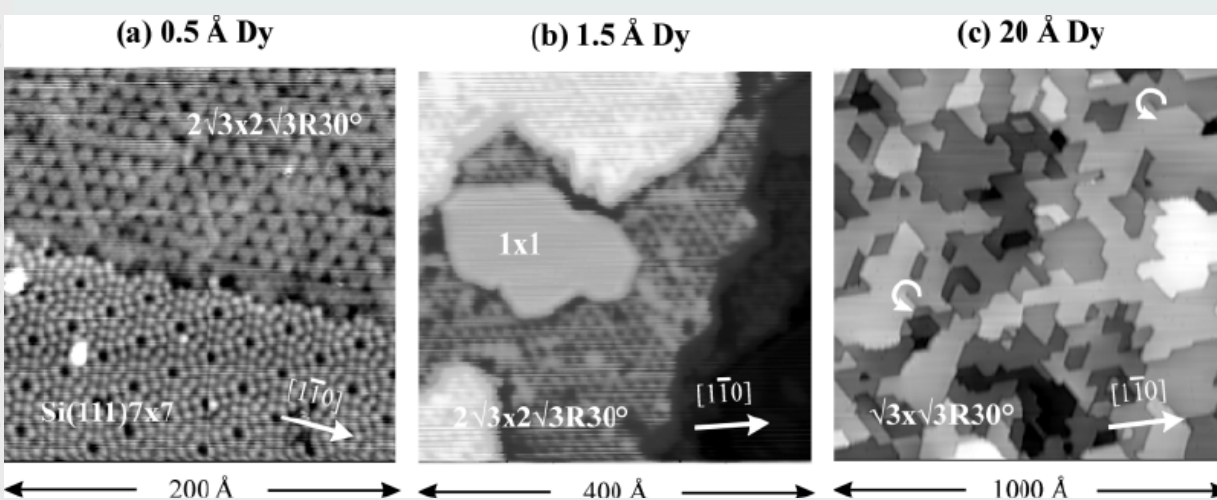


On the left another example of how a nanotube can be manipulated to form complex shapes: the 6 frames are a series of AFM images of a nanotube (orange) on a silicon substrate (blue). Not all steps are shown. The AFM tip is used to create the Greek letter "theta" from a 2.5 micron long nanotube.



Nanochemistry UIO

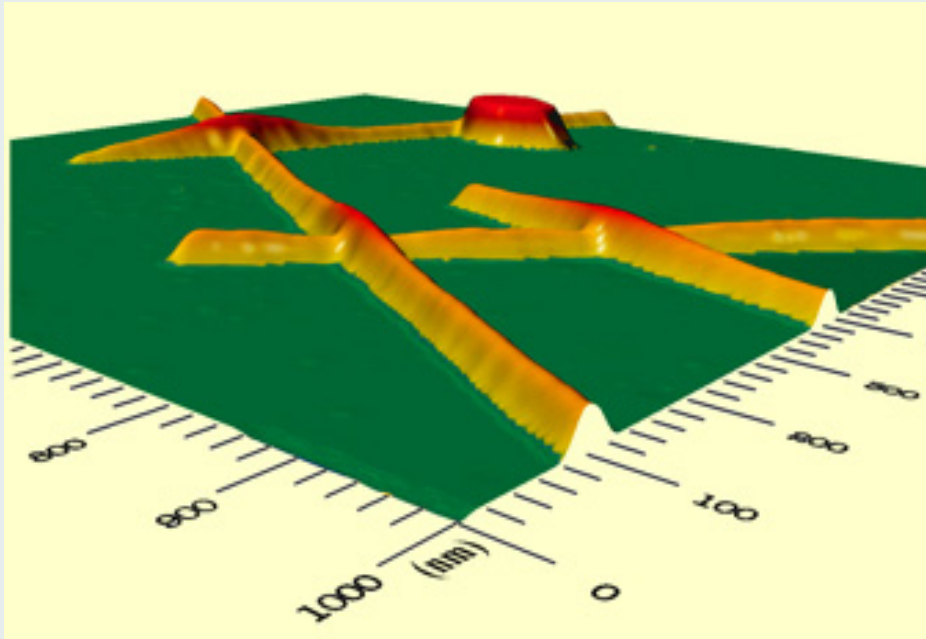
# Example 1: benzene on Si(001)



The silicide films were grown by deposition of thin Gd, Dy, Er, and Lu films on clean Si(111)7x7 surfaces and subsequent annealing at temperatures of 500 - 600 ° C. In this way, the silicides are formed by solid-state diffusion of Ln and Si atoms. For the STM experiments, [ultra-sharp tips](#) prepared by ion bombardment were used.

Nanochemistry UIO

# Scanning Probe Microscopies



Nanochemistry UIO

# Physical Effects and Methods

	Bond type	Electronic structure	Elemental analysis	Polycrystalline texture	Surface structure	Crystal defects	Local structure, CN, etc.	Crystal structure	Unit cell, space group	Amorphous or crystalline	Phase identification
X-ray diffraction	(✓)			(✓)	(✓)	(✓)	(✓)	✓	✓	✓	✓
Electron diffraction and microscopy			✓	✓	✓	✓		✓	✓	✓	✓
Neutron diffraction						✓		✓	✓	(✓)	(✓)
Optical microscopy				✓	(✓)	(✓)				✓	✓
IR spectroscopy	(✓)	(✓)			✓		✓				✓
UV, visual spectroscopy	✓	✓	(✓)			(✓)	✓				
NMR, ESR spectroscopy	(✓)	(✓)	(✓)			(✓)	✓				(✓)
Electron spectroscopy—ESCA, XPS, UPS, AES, EELS	✓	✓	✓		✓	(✓)	✓				
X-ray spectroscopy—XRF, AEFS, EXAFS	(✓)	(✓)	✓		✓	(✓)	✓				
Mössbauer spectroscopy	(✓)	(✓)					✓				

## Physical Effects and Methods

EPMA	Electron Probe Micro Analysis	Analyse der charakteristischen Röntgenstrahlung oder der Elektronenstrahlung $\Rightarrow$ Elementaranalyse
EMMA	Electron Microscopy with Micro Analysis	Analyse leichter Elemente
AEM	Analytical Electron Microscopy	komplexe Spektren, bisher wenig untersucht
XRF	X-ray Fluorescence (charakteristische Röntgenstrahlung, Moseleysches Gesetz)	
EDX	Energy Dispersive X-ray-Analysis	
EELS	Electron Energy Loss Spectroscopy	
AES	Auger Electron Spectroscopy (Sekundärelektronen)	
ESCA	Electron Spectroscopy for Chemical Analysis	$E_{Einfall}^{\nu} = E_{Bind}^{Elektron} + E_{Kin.}^{Elektron}$
XPS	X-ray Photoelectron Spectroscopy	$E_{Kin.}^{Elektron}$ wird gemessen $\Rightarrow$ Elektronenstruktur von Feststoffen und Oberflächen
UPS	UV Photoelectron Spectroscopy	
AEFS	Absorption Edge Fine Structure (XANES)	Oxidationszustände, lokale Umgebung
EXAFS	Extended X-ray Absorption Fine Structure	ausgewählter Atome
ESR	Electron Spin Resonance	Elektronenkonfiguration
EPR	Electron Paramagnetic Resonance	lokale Umgebung
ENDDR	Electron Nuclear Double Resonance	lokale Fehlstellen
Mößbauer	$\gamma$ -Strahlen-Resonanz	Elektronenstruktur
STM	Scanning Tunnel Microscopy	magnetische Struktur
LEED	Low Energy Electron Diffraction	Oberflächenstrukturen

