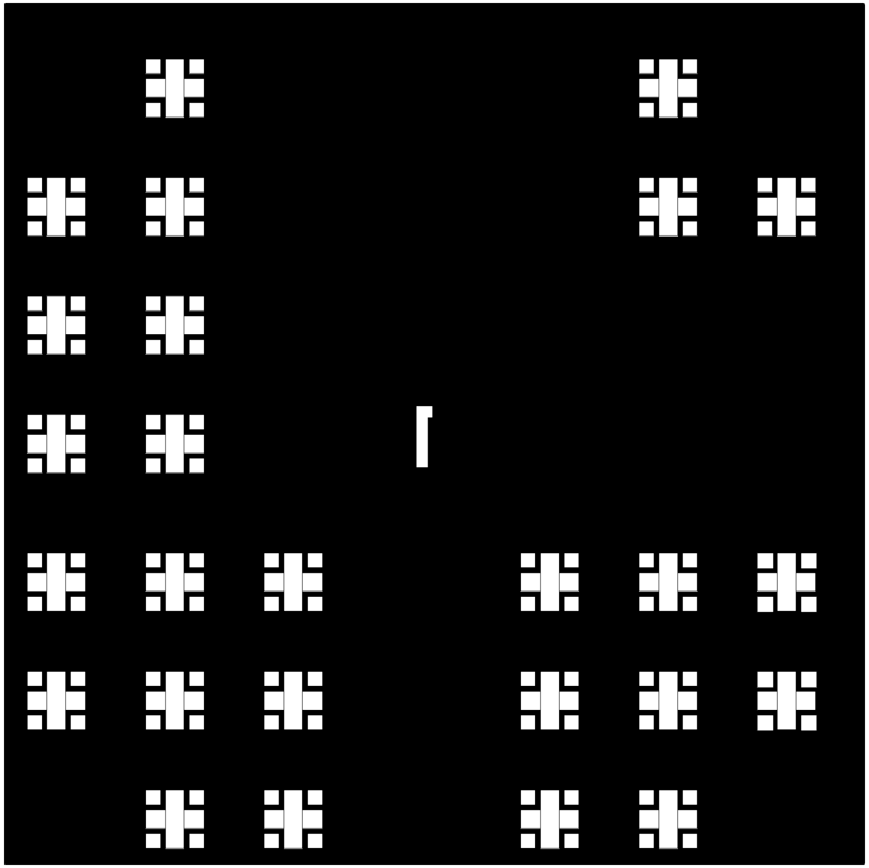
Fabrication

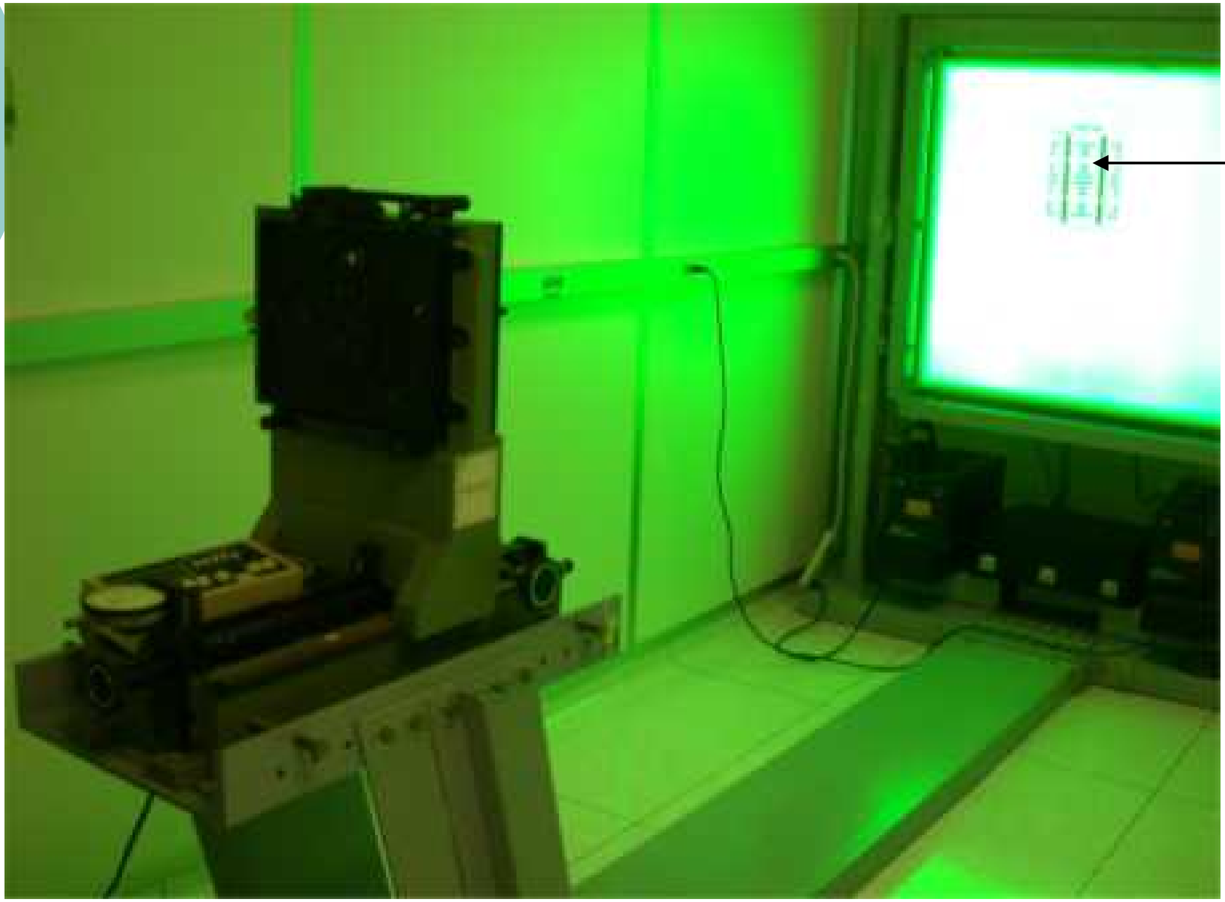
- “Top down” approach to nanotechnology
- This is overview, for more details take MAE courses by Marc Madou, Andre Shkel
- Thanks to Sungmu Kang for INRF images

Photomasks

Design geometry on computer.



Mask fabrication



transparency

After Exposure
Developer
Stop bath
Fixer

Dark room (1/20 reduction)

Spin on photoresist

wafer

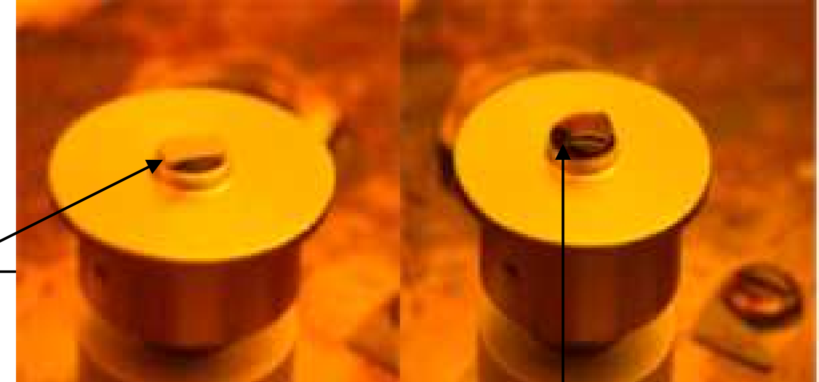


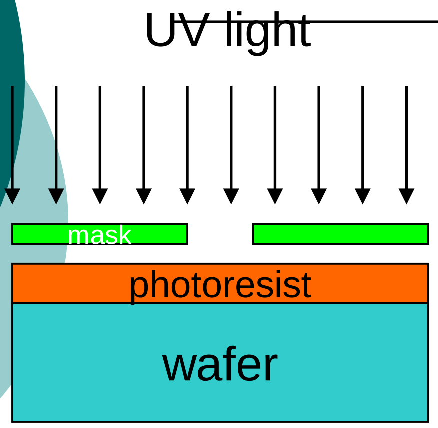
Photo resist

Photo resist spinner

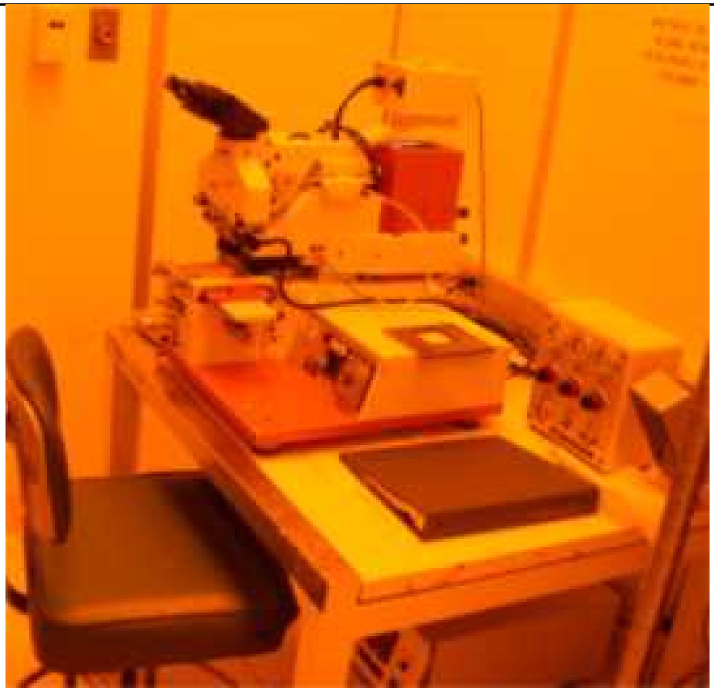
Soft bake

Oven for soft baking of photo resist (at 90C for 30 min)

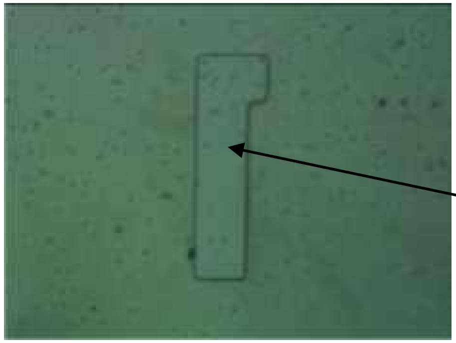
Expose to UV light



Development
For Shipley 1827
Water : MF351 = 5.5 : 1



Mask Aligner



Exposed regions dissolved in developer leaving bare wafer

This is the step which limits the spatial resolution.

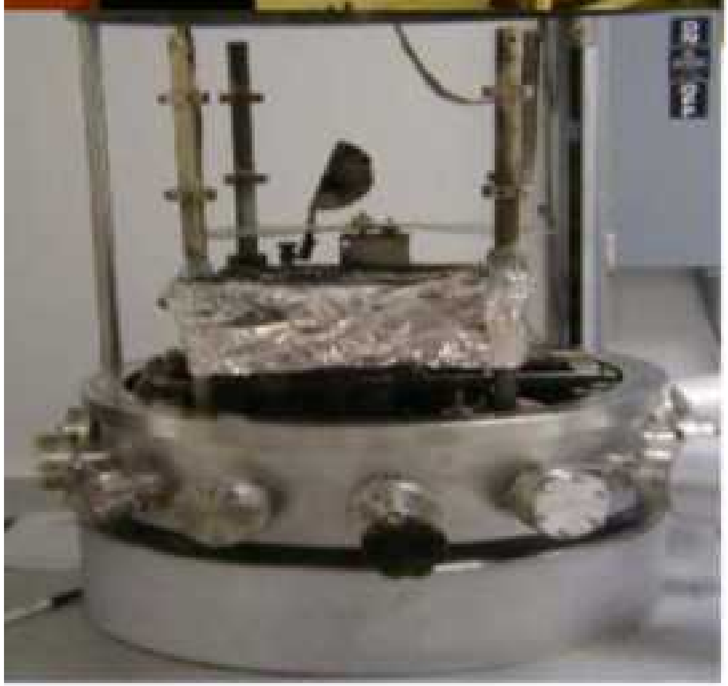
Thermal evaporation

Thermo evaporator

Alumina coated W boat

Useful for e.g.
Al, Ni, Au, Cr, Ti, NiCr, Pb, Sn

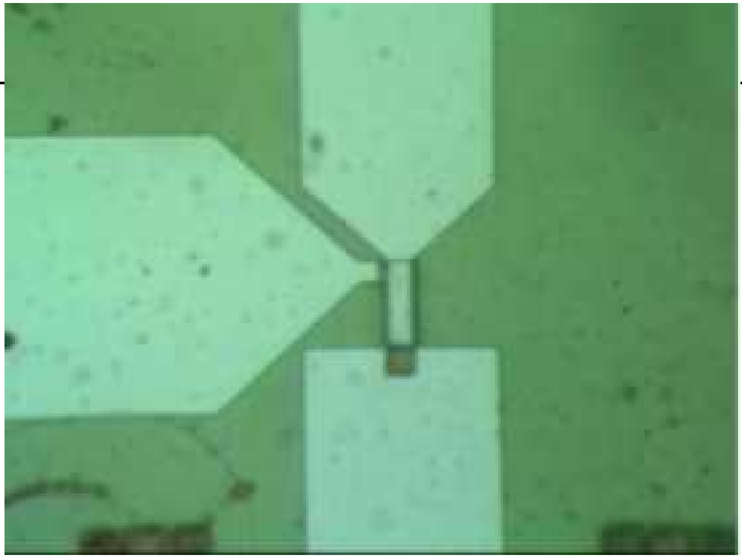
E-beam evaporation



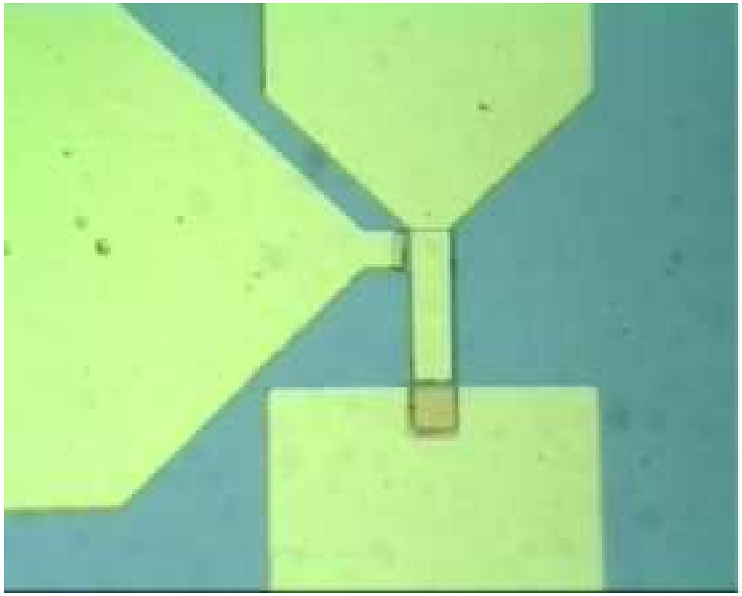
Electron beam evaporator

Au

Liftoff



Opening of photo resist for Ti/Au gate



After deposition of Ti/Au, then soaking in acetone

Resolution of optical lithography

$$R = \frac{3}{2}\sqrt{\frac{\lambda z}{2}}$$

Contact printing

z is resist thickness
(typically 0.1-1 μm)

$$R = 0.61\frac{\lambda}{NA}$$

Projection printing

NA is numerical aperture
(typically 0.5)

Light sources

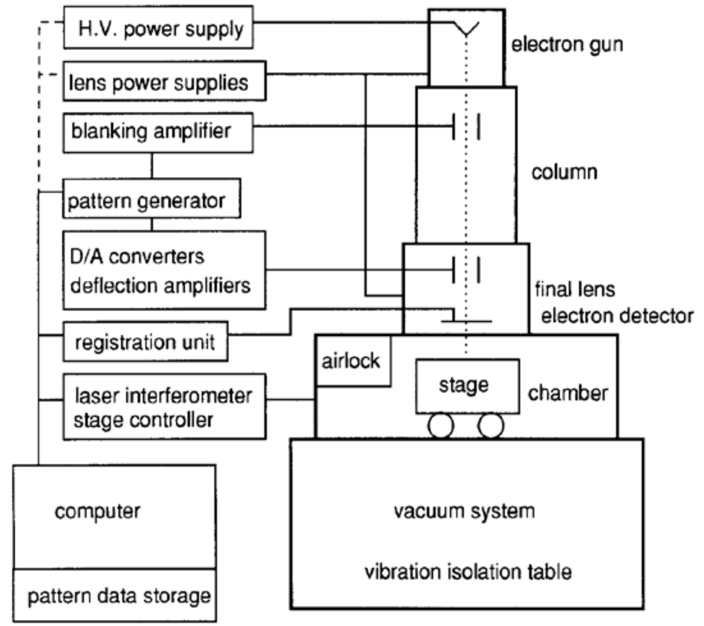
Source		λ	Resolution
Hg lamp	(g-line)	436 nm	400 nm
Hg lamp	(i-line)	365 nm	350 nm
KrF		248 nm	150 nm
ArF		193 nm	80 nm
F_2		157 nm	research

increasing cost ↓

Extreme UV, x-ray lithography research topics.
Difficulties lie in sources, and materials for optics and masks.

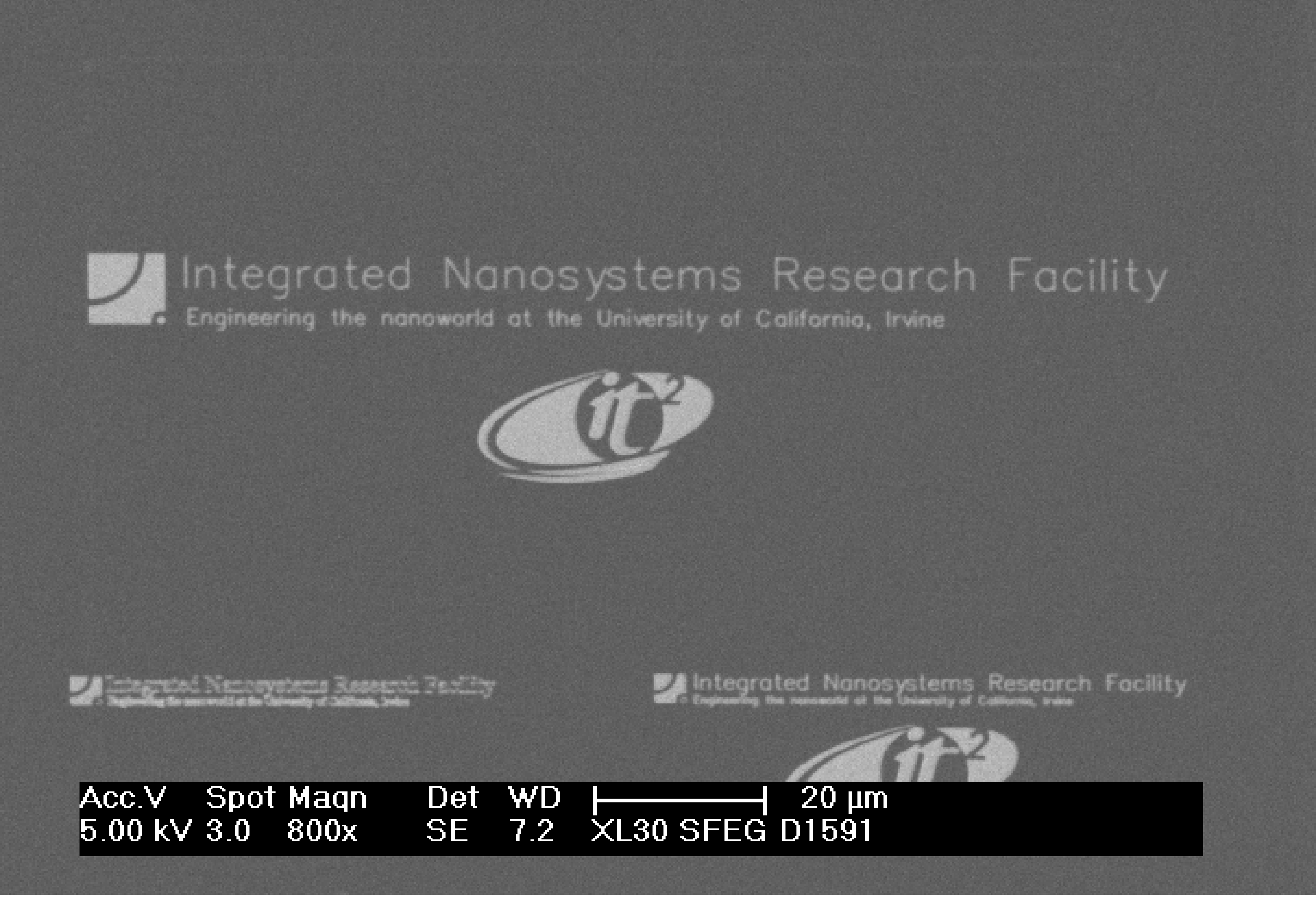
Electron Beam Lithography

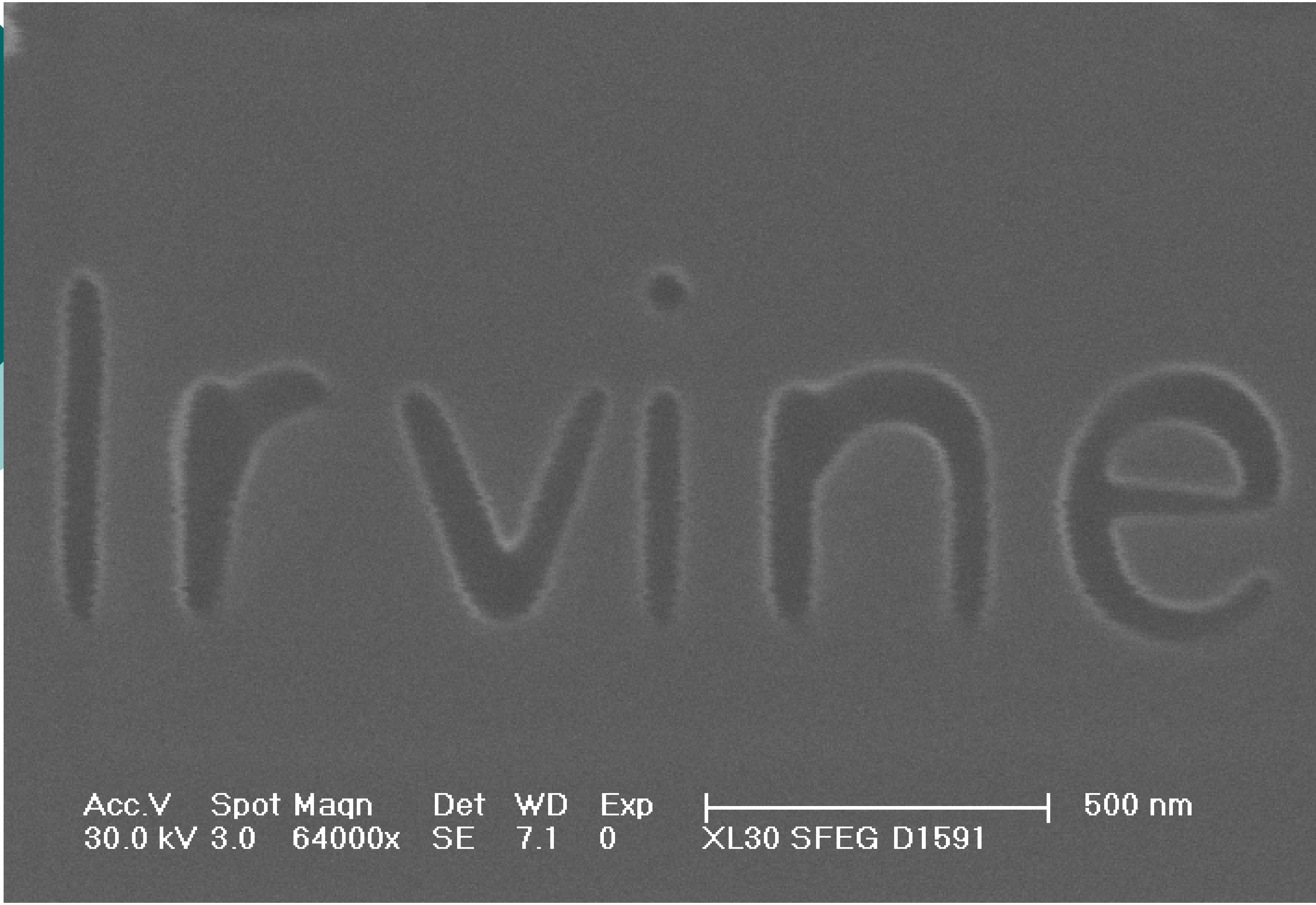
- Advantages
  - Resolution
    - electron wavelength small
    - beamsize 1 nm
    - resolution from scattering typically 10 nm
  - Flexibility
    - All patterns under computer control
- Disadvantages
  - Cost
    - Need high vacuum
    - Need precision electron focusing magnets
  - Throughput
    - Only one pixel exposed at a time
    - Not commercially viable except for a few applications

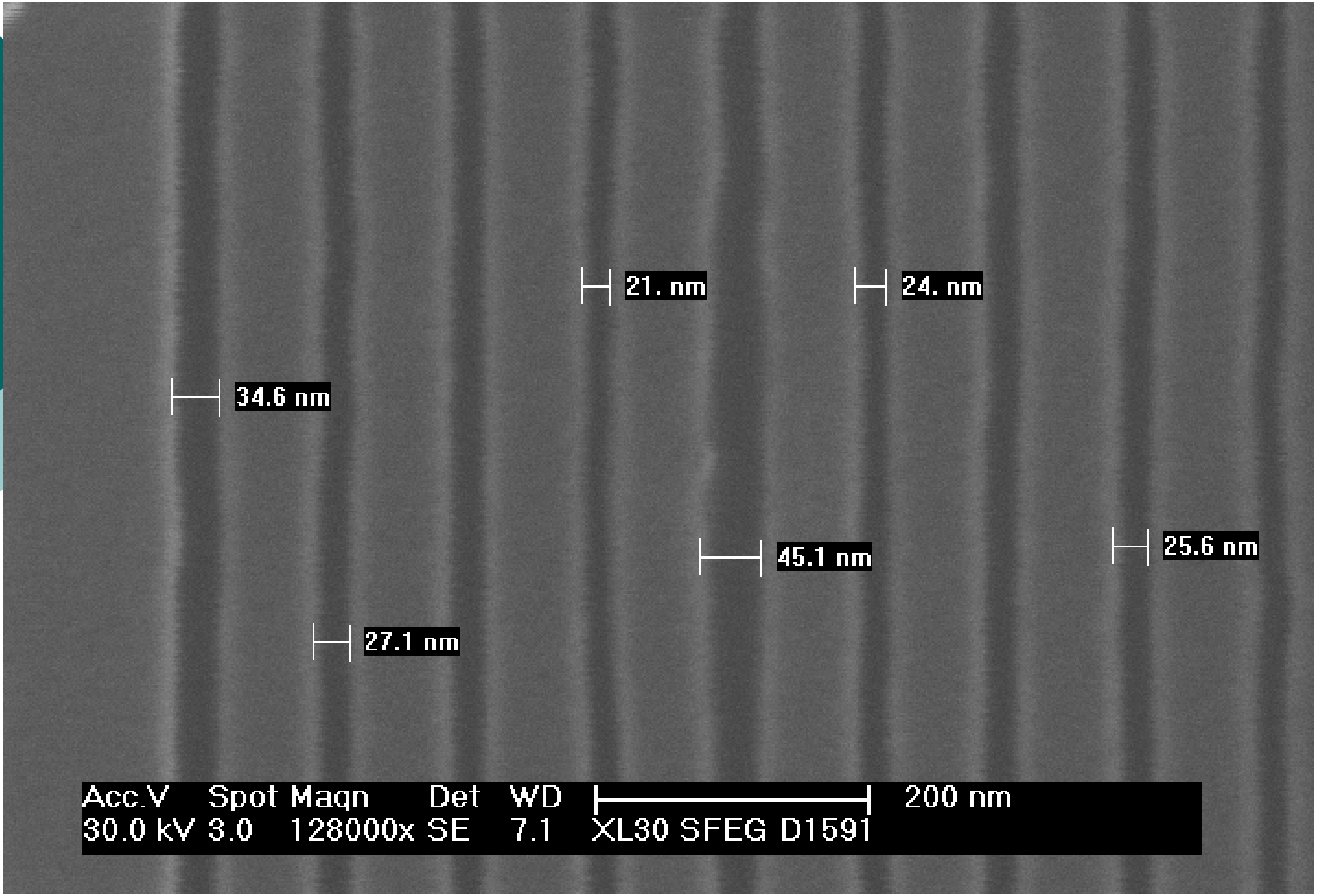


Reference: SPIE Handbook of Microlithography, Micromachining, and Microfabrication available at http://www.cnf.cornell.edu/spiebook/toc.htm

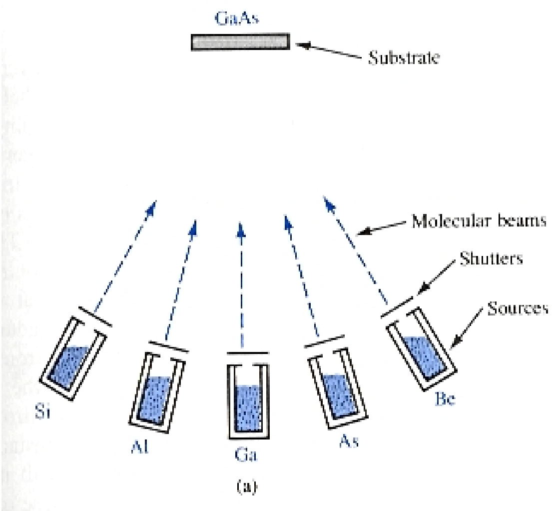
In spite of its disadvantages,
e-beam lithography is the main tool for nanotechnology research.

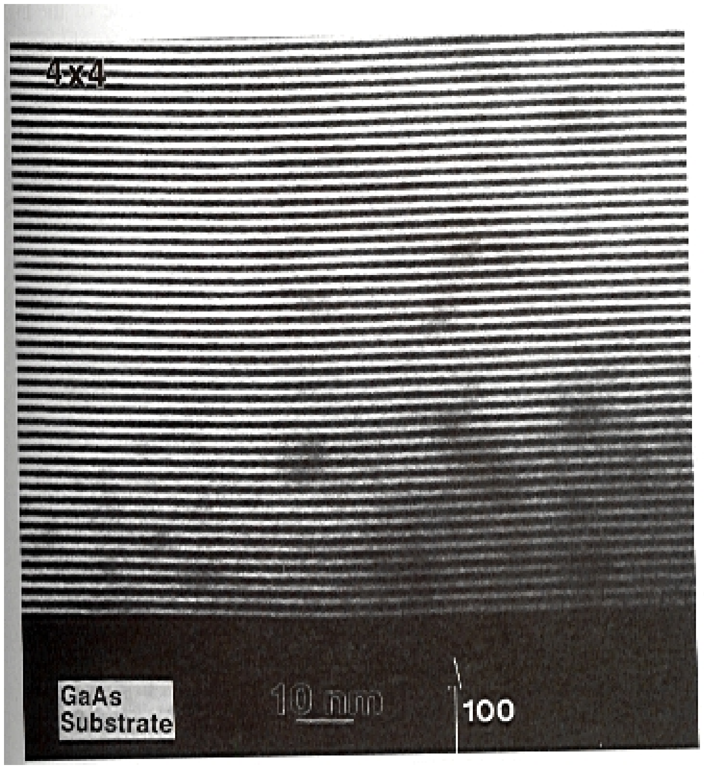

Integrated Nanosystems Research Facility
Engineering the nanoworld at the University of California, Irvine
Integrated Nanosystems Research Facility
Acc.V Spot Magn Det WD 20 µm
5.00 kV 3.0 800x SE 7.2 XL30 SFEG D1591


Irvine
Acc.V Spot Magn Det WD Exp
30.0 kV 3.0 64000x SE 7.1 0
500 nm
XL30 SFEG D1591


21. nm
24. nm
34.6 nm
45.1 nm
25.6 nm
27.1 nm
Acc.V Spot Magn Det WD 200 nm
30.0 kV 3.0 128000x SE 7.1 XL30 SFEG D1591

Molecular Beam Epitaxy (MBE)



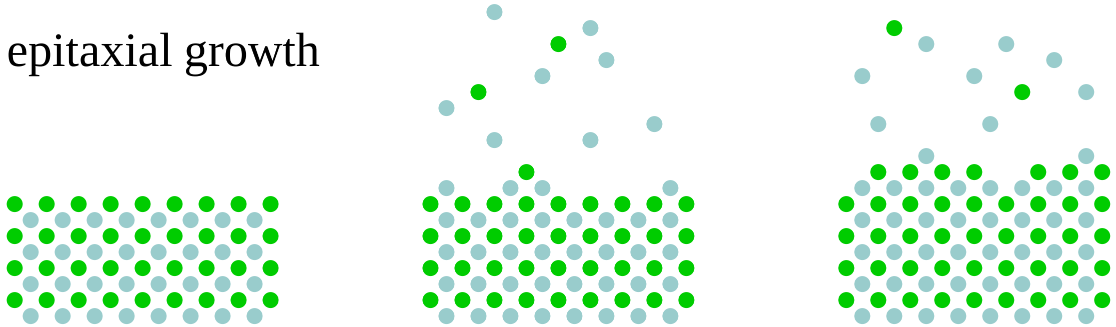


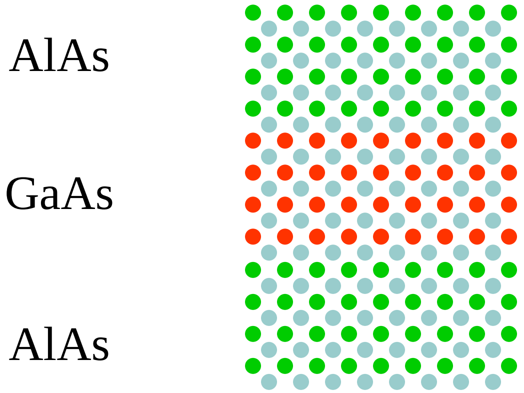
4 atom per layer!

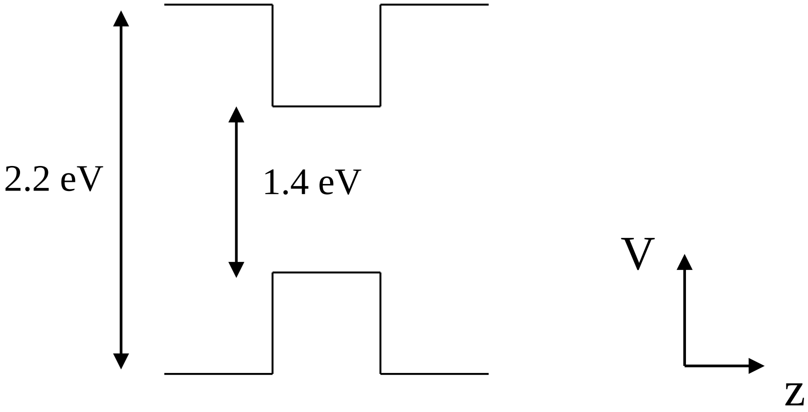
(From Streetman, Solid State Electronic Devices)

MBE

epitaxial growth





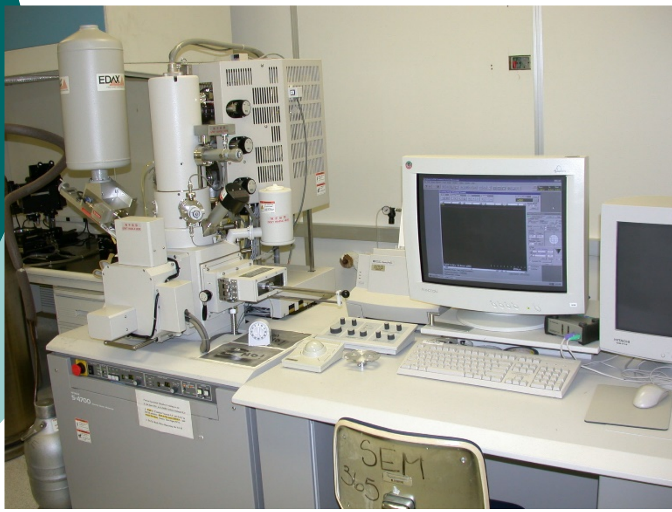


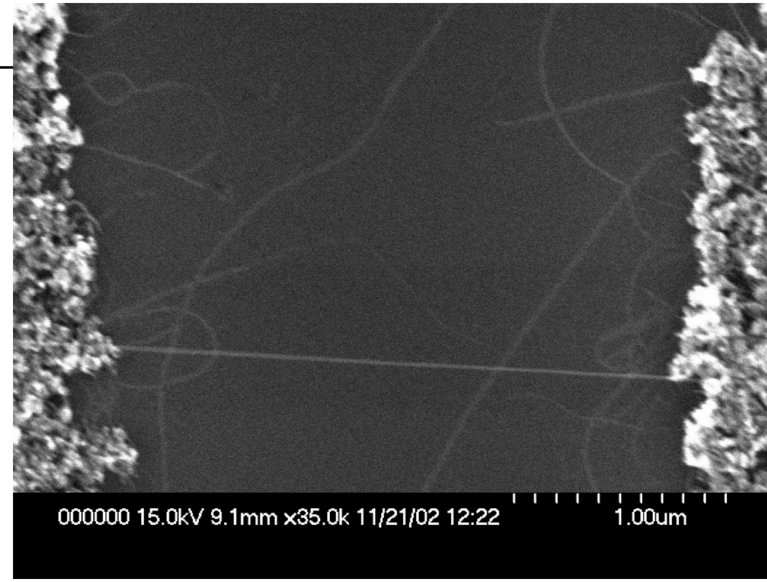
Also InP, InGaAs, InAlAs, InGaAsP …

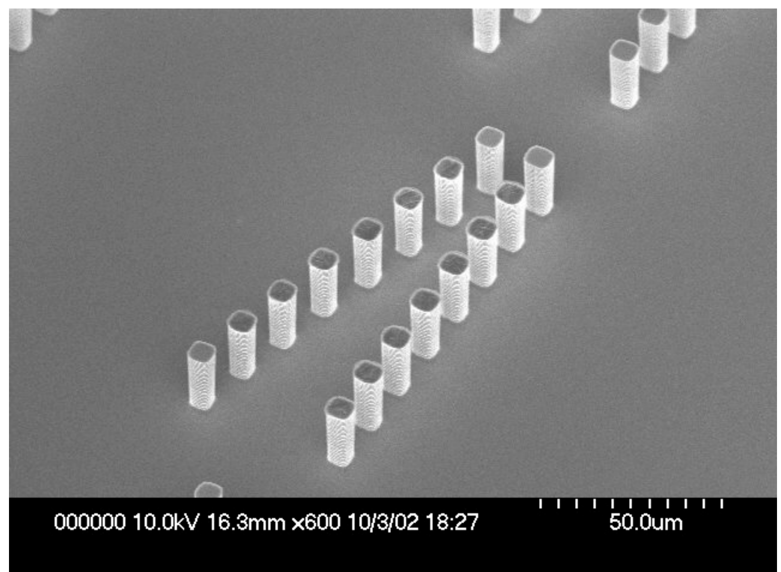
Characterization

- Optical microscopy cannot see better than wavelength of light, ~ 1 μm
- Scanning electron microscope (SEM)
- Transmission electron microscope (TEM)
- Scanning probe microscopy (SPM)
- Atomic force microscope (AFM)

SEM

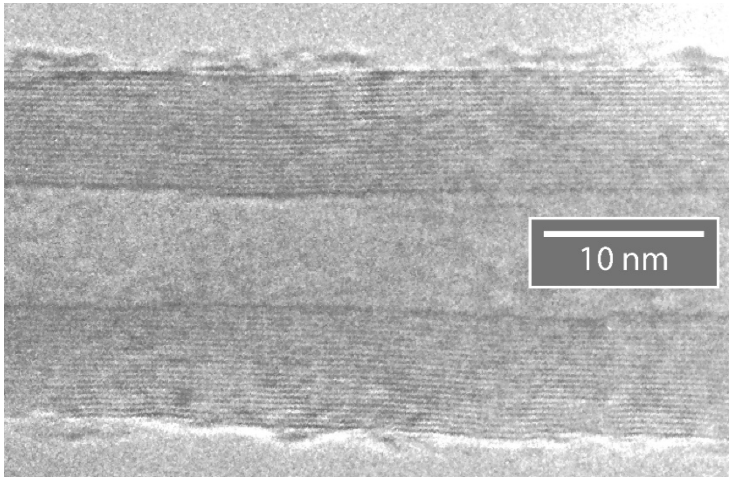






- Advantages:
  - resolution to 1 nm
  - fast
  - 3d structures visible
  - back-scattered x-ray spectrum gives compositional information
- Disadvantage
  - must be in vacuum environment (not good for bio)
  - expensive
  - samples must be conductive

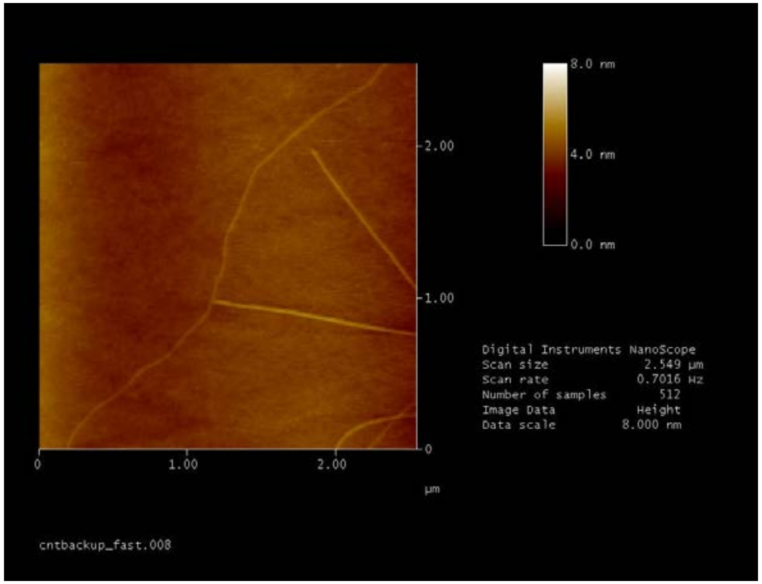
Multiwalled carbon nanotube



Shengdong Li, submitted

- Advantages
  - resolution < 1 nm
  - fast
  - diffraction pattern gives crystolographic info
- Disadvantages
  - expensive
  - high vacuum
  - sample must be thinned

SPM/AFM



- Mode of operation
  - non-contact
  - tunneling
- Advantages
  - works in air or liquid
  - angstrom resolution possible
  - can image individual atoms
  - probes various quantities
    - conductance
    - magnetism
- Disadvantages
  - extremely slow
  - many minutes for one image

Length scales

- Atoms
  - ~ angstrom 10^{-10} m
- Light
  - wavelength ~ μm
- Electrons
  - De Broglie wavelength = h/p (quantum mechanics)
  = sqrt (150/V) in angstroms (V is energy in volts)
  ~0.1-10 nm
  - If circuit element is about the size of an electron wavelength, wave nature will be *crucial*
  - Conductance quantized at these small scales in units of e^2/h
- Mean free path (MFP)
  - 10^{-10} m in metals at room temperature
  - 10^{-4} m in ultra high quality semiconductors at low temperatures

Energies

- Electronic transition energies
  - ~ 1-10 eV
- Fermi energy
  - 1-10 eV in metals
  - 1-10 meV in semiconductors
- kT
  - 30 meV at room temperature