Useful NanoTechnology: a view from the lab

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Physics
Quantum
Optoelectronics

Chemistry

Electronics
Southampton University Microelectronics Centre

Computer Science
High Performance Computing Group

Maths

EPSRC/Royal Society NanoMaterials Prototyping Facility

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Useful NanoTechnology: a view from the lab

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• How did we get here? How do you use Nano?

• Nano in the Lab

• Nano out of the Lab

• Visions for Nano
Technological Memory

- switch physical states

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Computer data
01110101011010101
10100101011010101
01010101011010101
01000101011010101
01000101011010101
011010101001100
00101011101100111
10101001010101010
```

"0"     "1"
Physical Representation: what Nano do you

- How is your bank balance stored?

1) CHARGE

- 100,000 electrons sitting on a metal plate
- charged up in 1ns
- decays in 1 ms

- electrostatics
- memory chip
Shrinking memory

- Every 4 years, transistors halve their size
- Memory stored in each chip doubles every 2 years
- Cost per bit drops at the same rate

shrinking technology has continued over a factor of 1,000,000!

- will it stop?
- most transistors need electrical power
Shrinking memory

now have chips with more transistors
than people on the planet,
in area of a postage stamp
Physical Representation: what Nano do you

- How is your bank balance remembered?

2) SPIN spinning or orbiting electron
has ‘spin’
(really quantum mechanical)

a billion electrons
spinning inside a magnet
flipped in microseconds

billions of magnets
on each hard disk
The Future is still .... smaller!

1) single electrons on an island

nanometre sized matter

reliable fragments matter to hold memory

Ref. 1×1 μm
PROBLEM: *small things are difficult and expensive to make*

**top down**
- electron beam lithography

**vs**

**bottom up**
- nano-templating
  - ‘dirty’
Templating Nanomaterials

- Self-assembly mould in soft materials
- Cast into hard materials (cannot carve directly)
- Retains detail on all size scales (huge to fine)
- Quick, cheap, durable

• Nano-organised materials/
  ‘Metamaterial’
  new properties
  not just mixtures of ingredients

• Self-assembly
  sophisticated 3D architectures
  control on nanoscale
  directed and spontaneous

illustrates classic advantages of casting:
Written in the sand

Mesopotamia (Iraq)  Egypt  3000-1000BC

wax, sand
1-100 nm
Soap for Nano-Assembly

template self-assembly

hexagonal

side view

12nm

25nm

nano-casting

Electro-deposit

Soap removal

Liquid crystal template

$M^2^+$$M^2^+$$M^2^+$

cconducting substrate

electrodeposited semiconductor film

$M^2^+$$M^2^+$$M^2^+$

cconducting substrate

mesoporous semiconductor film

cconducting substrate
Nanoporous solar cells

soap nano-template  CdTe cast

domains

- squeezes electrons inside: new properties
- better efficiency solar cells
- new materials: optical, electronic
eg. negative refractive index
10-1000 nm
Capillary forces: control ordering plastic spheres 50nm-20μm

Evaporation leaves self-organised structure

Electro-deposit metal & dissolve latex spheres

durable, easily grown, metallic cast

Diffracted light shows domains:

Increasing film thickness →

1 mm

350 nm radius
Molecular Sensing with NanoSurf

shake a molecule

vibrating bonds absorb packets of energy
so re-emitted light has different colour

but VERY VERY weak

Molecules on this surface can be shaken by light
a billion times more effectively: sensors

commercialised (Mesophotonics)

useful for diagnostics:
- medical, bio, pharmaceuticals
- homeland security,
- environmental monitoring
So WHEN do we think about the implications of Nano-research?

about vision, about ethics in the research process
- grant, lab, write, submit, talk, publicise...

when should we think?
- eg. for Raman NanoStructured Substrates?

What do researchers want? .... Goals for science projects
- ‘surprise’ (straw men)
- projected utility
Nano-research is typically ‘free research’

Most research is NOT strategically directed
  - solutions to which problem?

‘Can we understand what happens if we try to make ...’
  - evolution of toolkit
  - playground for novel ideas/novel challenges
  - train students to think this way

Southampton: Physics with NanoScience degree
Nano as toolkit, Nano as philosophy
How does this Nano-research emerge into the public domain?

Effect of hype

- Strong pressure on scientists to shout results of projects
- Media coverage is disconnected (101 reports of cure for ....)
- ‘This could be used for...’ when?
- response of some colleagues is to avoid exposure
  (‘the next GM...’)
- public: subtle disbelief and interest
Three Nano-dystopias....

Nano-pollution: new materials
  - health, eg 10yr latency for sterility,
  - no current monitoring
  - fears: environmental pollution

Nano-bot:
  - self-cloning, resource disaster
  - fears: biotechnology, GM

Nano-assassin: miniature military
  - invasive, surveillance
  - terrorism, AI
• Nano-dystopias and Nano-utopias equally unrealistic

• Takeup will emerge from realistic practical solutions

• Nano focus is really a paradigm for how research works
NanoTechnologies: media and publics
- how do Nano scientists choose to develop their research
  when do they think about vision, ethics in the research process (grant, lab, write, submit, talk,...)
- goals for science project: what gets high impact
  - surprise (straw men)
  - utility - projected scope
  most research is not of this type: (in Nano)
  ie. strategic, directed to complete solution of defined problem
  more like 'will try to understand...'
  - progress: being able to do better/more functioning Nanomachine
    evolution of toolkit
    playground

(Physics with Nano at Soton: includes awareness of ethics, publics: Nano: toolkit + philosophy)

- effect of hype in subject
  strong pressure on scientists to shout results of projects
  media coverage is disconnected (101 articles report gene for cancer...)

- 3 dystopias of Nano
  Nano-assassin: miniature military - invasive, surveillance - terrorism, AI
  Nano-pollution: health, eg 10yr latency for sterility, no current monitoring - environmental
  Nano-bot: self-cloning, resource disaster - biotechnology, GM

- 3 utopias of Nano:

so how do we try and make things on the Nano scale: nanotemplating?
QD-DNA
SERS!?
**DNA-QD Assembly**

Melvin (ORC) Brown (Chem) JJB

**Rapid Sequencing (Basic Tech)**

Morgan (ECS) Zheludev (Phys) Roach (Chem)

Combined optical, impedance and magnetic sensing systems on a chip.

DNA analysis using optical bar coding.
Future....where can we go?

You decide.....

Nano- is the interdisciplinary science and technology of the 21st Century

quantum memory
controlling spin
molecular circuits
switching light
new meta-materials

Outlook

- Science and Technology:
  Nano- and Bio- this century will leap towards devices and dreams

- how will this change society?

- what does society want from NanoTechnology?
**NanoPhotonics & NanoElectronics**

Nanostructure material on scale of
- optical wavelength (100nm)
- electronic wavelength (1nm)

near-field optics
modify optical modes

Tuneable electronic states
modify interactions

Conventional paradigms

New paradigms

100nm nanotemplate & growth

- films
  - semiconductor microcavities
  - Quantum Dots

- fibres
  - spherical nanocavities
  - nanoporous metamaterials

- Conventional paradigms
- New paradigms