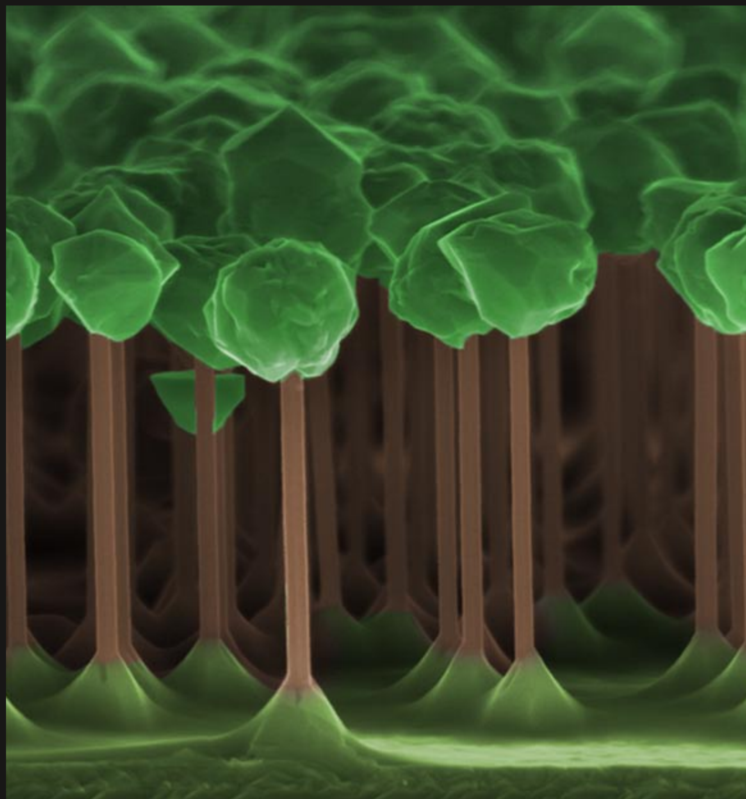


Nanotechnology

The growth of
the nano concept in Lund.

The nanotechnology in Lund

Lars Samuelson, Professor in Semiconductor Electronics at the Division of Solid State Physics, started the Nanometer Consortium (NMC) in 1990.

This consortium brought together chemistry, physics electronics and theory for the development of new physics, technology and materials science on the nanometre scale.

(1 nanometre, 1 nm = 10^{-9} m)

nm structures

Aerosols and Solid State Physics

One example of the interdisciplinary projects being carried out at the NMC is that with the Aerosol Group at the Division of Nuclear Physics.

It was shown that semiconductor structures could be made using size-selected aerosol particles. This project, which is led by Knut Deppert, has been very successful.

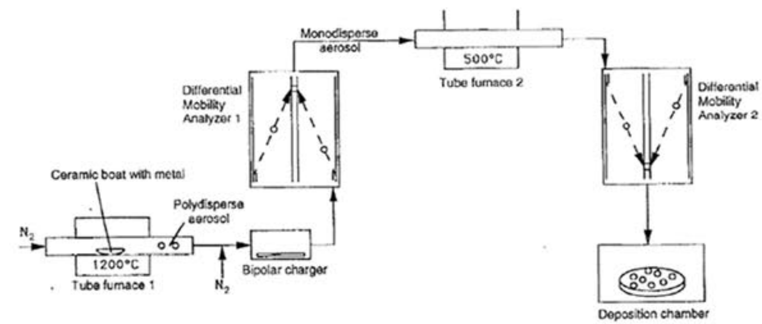
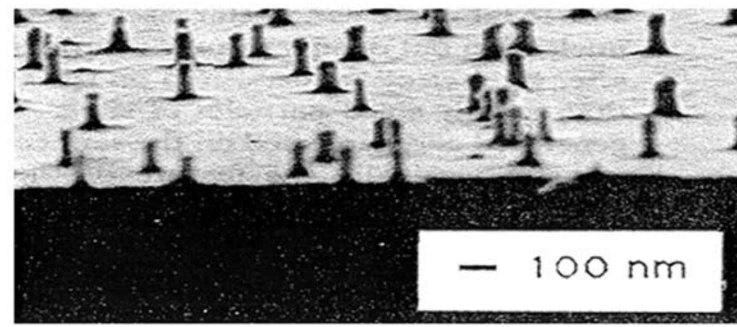
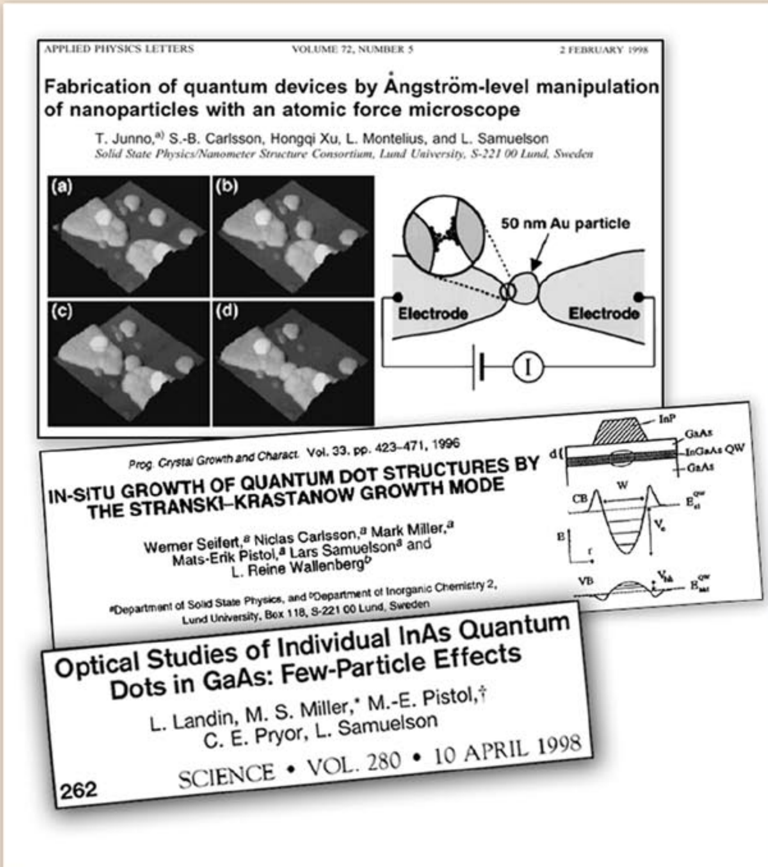


Illustration of the aerosol generation system in which nanoparticles with a narrow size distribution are made and deposited in a controlled way onto a substrate.



Scanning electron microscopy image showing freestanding columns of indium phosphide after an indium phosphide surface covered with silver particles has been etched.

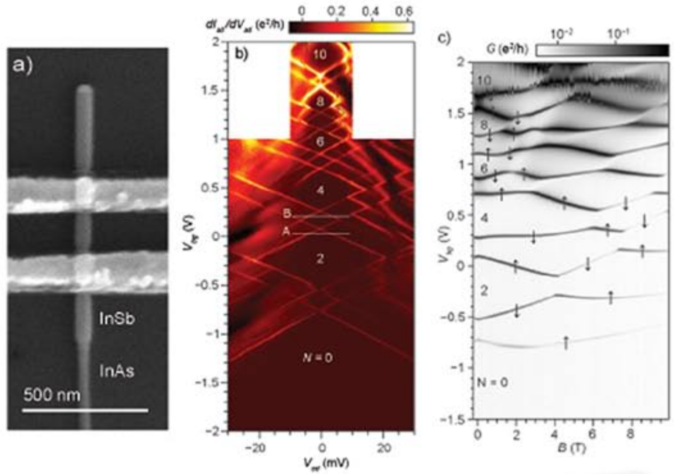
Quantum dots



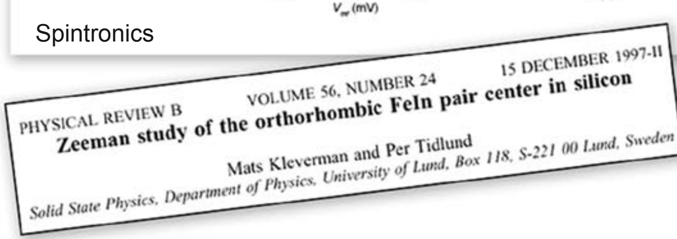
Using the method of MOVPE, quantum dots were made during the 1990s. These are small semiconductor structures in which the electrons cannot move in space, but can only be found in different energy levels.

Quantum dots are interesting in many fields such as optics and quantum components, as well as in theoretical research.

Magnets



Spintronics



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Zeeman study of the orthorhombic FeIn pair center in silicon

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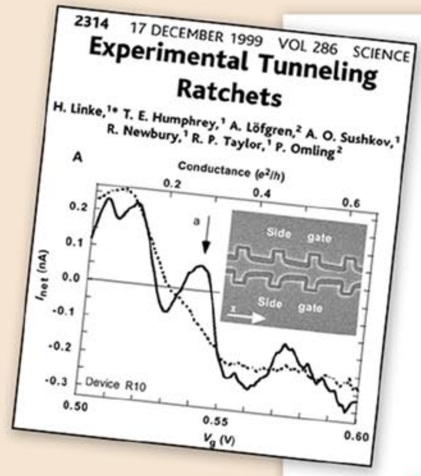
During the 1990s, many successful experiments were carried out at the division in which magnetic fields were used to split spectral lines using the so-called Zeeman effect.

After this, researchers at the division started using magnetic fields to investigate the magnetic characteristics of electrons in spintronics, a completely new field of special interest in logic circuits.

Ratchets



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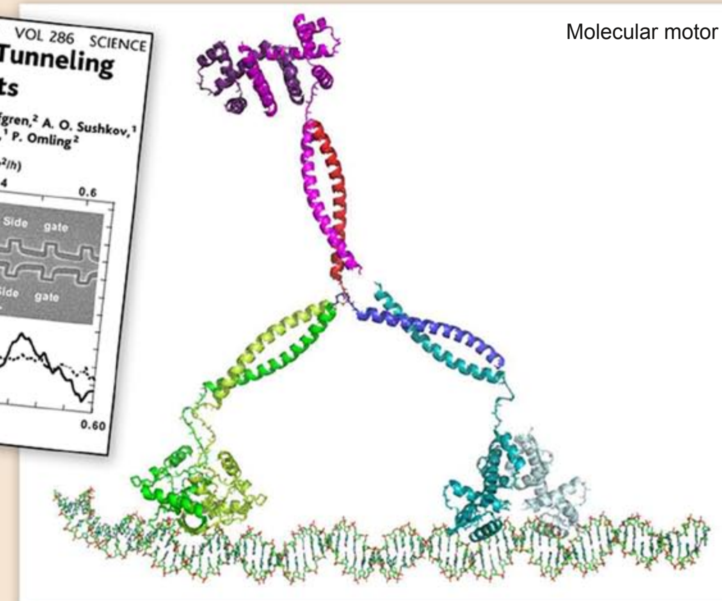
Experimental Tunneling Ratchets

H. Linke,[1*] T. E. Humphrey,[1] A. Löfgren,[2] A. O. Sushkov,[1] R. Newbury,[1] R. P. Taylor,[1] P. Omling[2]



At the end of the 1990s, nanostructures called ratchets were made, which allow electrons to move in one direction only. In this way it is possible to control the flow of particles.

The division also started to carry out research in biology, and the Bio Group has made ratchets from proteins. These move along a DNA molecule in one direction, forming a so-called molecular motor.

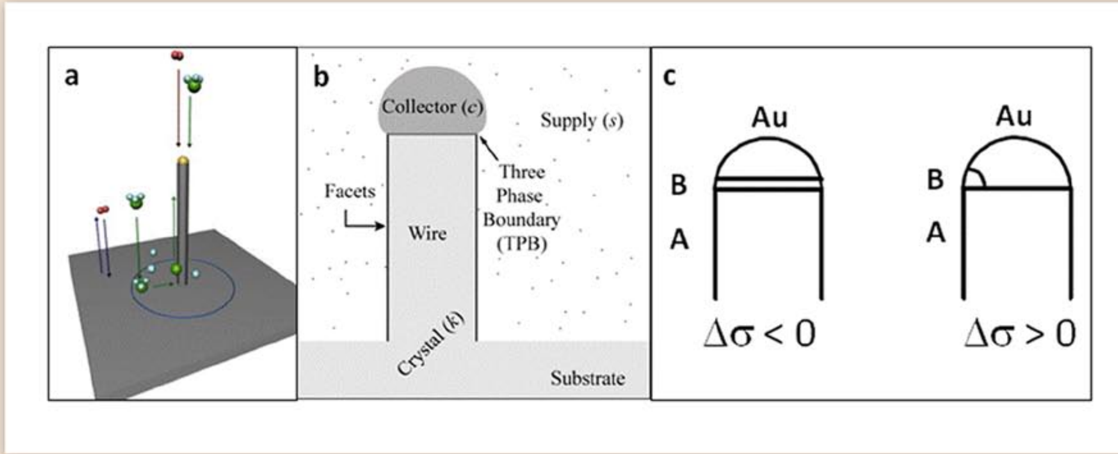
Nanowires & Solid State Physics

In 1995, Lars Samuelson visited a research department at Hitachi in Japan, where they had been successful in growing nanowires of gallium arsenide.

Lars realised that resources were available in Lund to develop this technique, and upon his return he started work in this field.

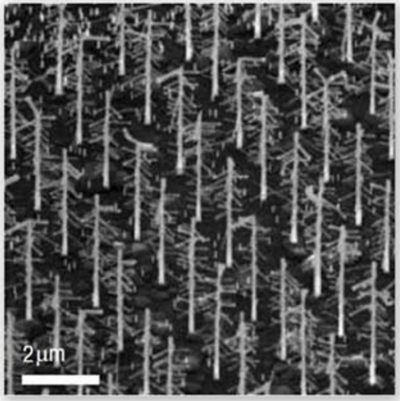
IB	IIB	IIIA	IVA	VA	VIA
		Boron B 5	Carbon C 6	Nitrogen N 7	Oxygen O 8
		Aluminum Al 13	Silicon Si 14	Phosphorous P 15	Sulphur S 16
Copper Cu 29	Zinc Zn 30	Gallium Ga 31	Germanium Ge 32	Arsenic As 33	Selenium Se 34
Silver Ag 47	Cadmiuim Cd 48	Indium In 49	Tin Sn 50	Antimony Sb 51	Tellerium Te 52
Gold Au 79	Mercury Hg 80	Thallium Tl 81	Lead Pb 82	Bismuth Bi 83	Polonium Po 84

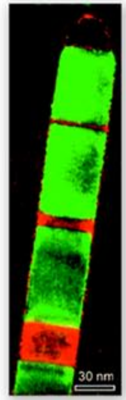
Part of the periodic table.
The blue-highlighted elements are those mainly used at the Division of Solid State Physics to make semiconductors.

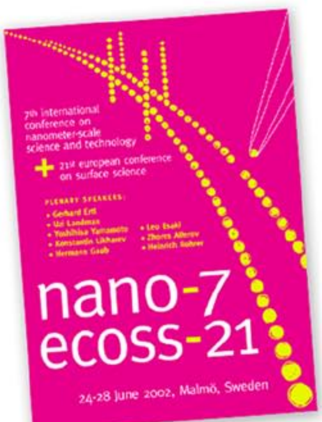


Nanowires are typically about 1 - 2 micrometres (μm) long and about 20 - 200 nm in diameter. They usually consist of two elements from groups III and V in the periodic table, but there are examples of combinations of elements from groups II and VI, alloys of three or four elements, or only group IV elements. Gold is often used as the catalyst for growing nanowires.

Nanowires grow in importance







Nanowires now play a central role at the Division of Solid State Physics, and the day-to-day work of most research groups is influenced by nanowires.

Attention was directed towards Lund in 2002, as researchers here were able to grow nanowires with a heterogeneous structure, nanowires with segments of different materials, in this case indium phosphide and indium arsenide.

In the same year, the division organised the 7th Nano Conference.

In 2004 the division was also able to demonstrate the growth of *branches* on nanowires, forming *nanotrees*, and even whole *nanoforests*!

The degree in nanotechnology

The first seminar for nanoscience students in the spring of 2004. Groups of 2-3 students present examples of the use of nanotechnology in the areas covered by the programme.

The left side photograph shows the demonstration of a hydrophobic shirt made out of functional material. The audience consists of fellow students, upper secondary school students, representatives from industry, alumni och lecturers involved with the programme. This kind of seminar is held every year for first-year students.

The interdisciplinary nature of nanotechnology inspired Lars Samuelson to develop a research-based 4½-year programme in nanotechnology.

The first group of students enrolled in the programme for Engineering Nanoscience in 2003. The programme is mainly based on studies in materials science, physics, electronics and biology.

The Nanochurch

The expansion of the division led to a need for more space and new equipment. An extension was built onto the Berzelius Lab, which was completed in 2006/2007. As the shape of the building resembles a modern church, it has become known as *the nano church*.

As well as a new laboratory, the Nano church also includes an area for seminars, called *the Creative Space*, or K-space.

The cleanrooms

The nano church has several cleanrooms that house equipment for the growth of crystals and the fabrication and characterisation of nanostructures. The cleanroom with the highest classification is ISO class 5, which means that no more than 100,000 particles larger than 0.1 µm are allowed per cubic metre.

The beginning of the 21st century

Four main areas of research are currently being pursued at the division today:

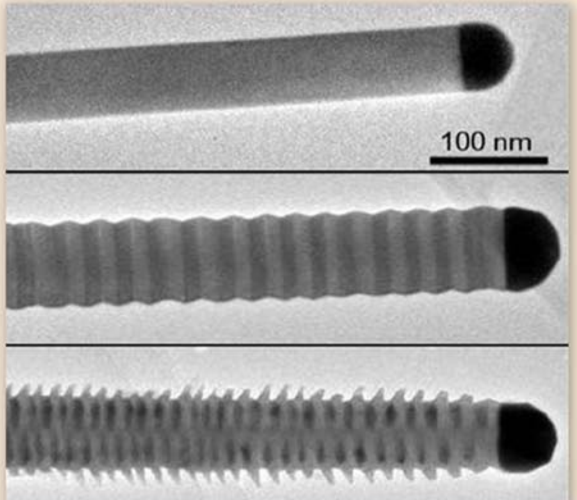
Nanomaterials
Nanophysics
Nanodevices
Life sciences

The success of the NMC means that activities at the division extend far beyond the Nanochurch. The facilities at the Division of Solid State Physics are used by over 200 researchers from 20 divisions of 11 departments, both within and outside Lund University.

A programme for commercialisation has led to the foundation of several spin-off companies and engagement in a number of EU projects.

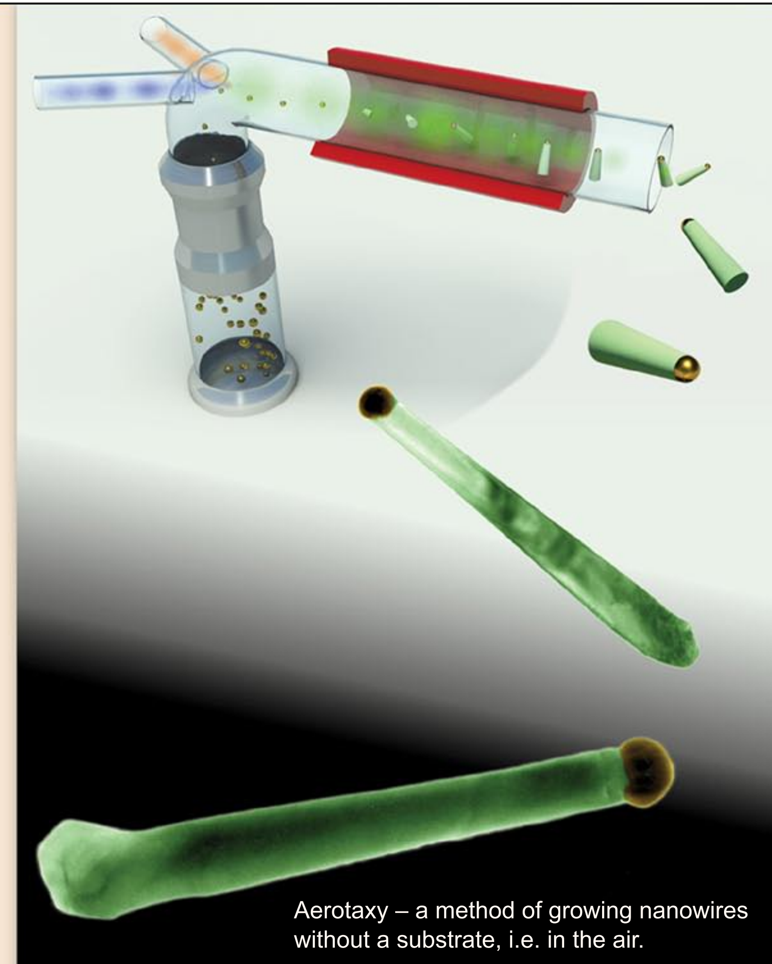
The scanning electron microscope is an important tool in the study of nanostructures.

Nanomaterials



Nanowires with and without a heterogeneous structure.

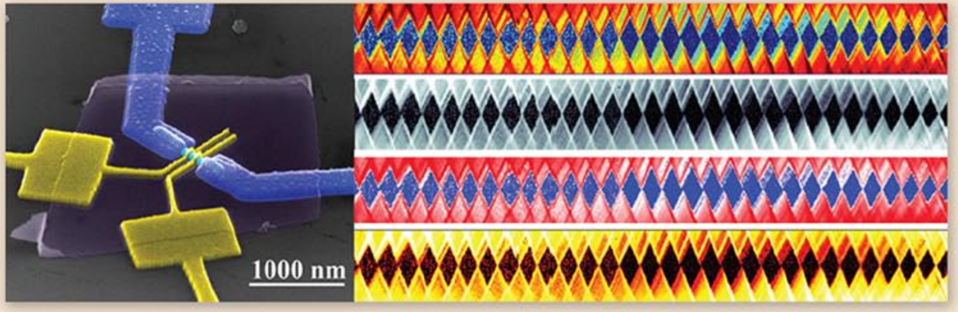
Research in nanomaterials includes materials science, crystal growth and nanostructure fabrication.



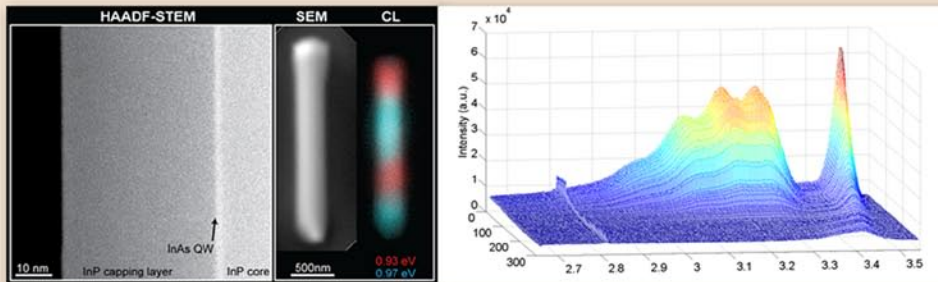
Aerotaxy – a method of growing nanowires without a substrate, i.e. in the air.

Nanophysics

Research in the field of nanophysics includes quantum transport and optical physics.



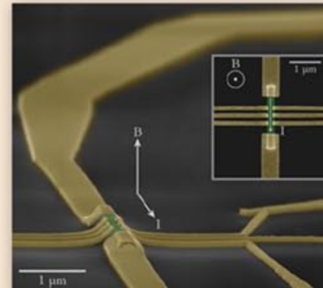
Electron transport in nanostructures includes the search for Majorana fermions and studies of Coulomb diamonds.



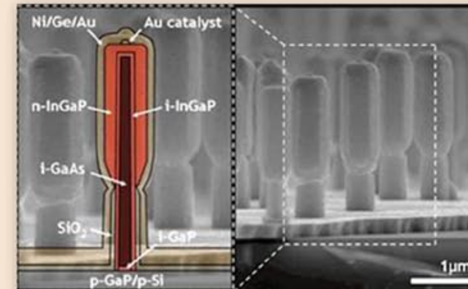
Photoluminiscence. This method gives high spectral resolution for the optical characterisation of semiconductor materials.

Nanodevices

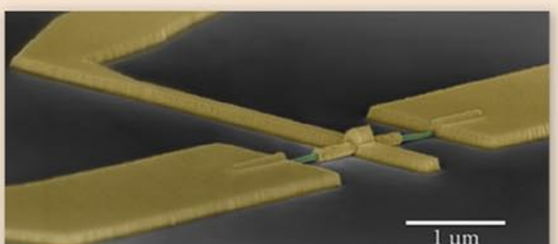
Research in the field of nanodevices includes nanoelectronics and optoelectronics.



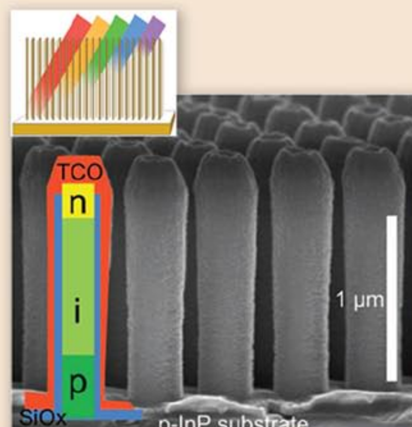
The Hall effect in a single nanowire.



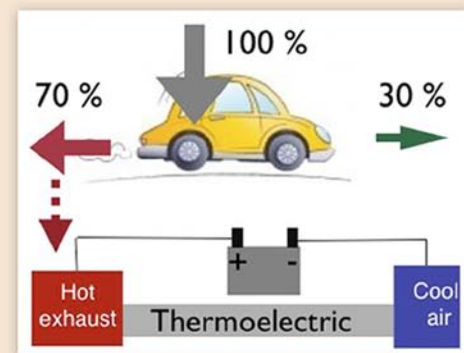
LEDs and *on-chip* optoelectronics.



Transistors



Solar cells

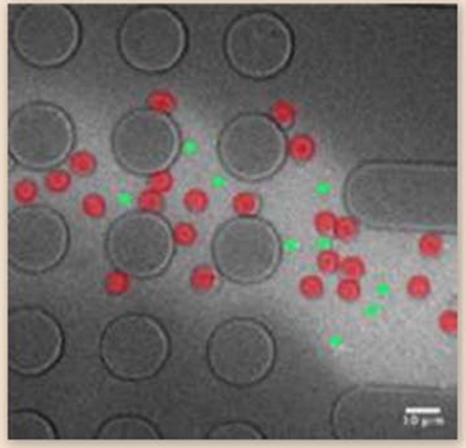


Thermoelectricity

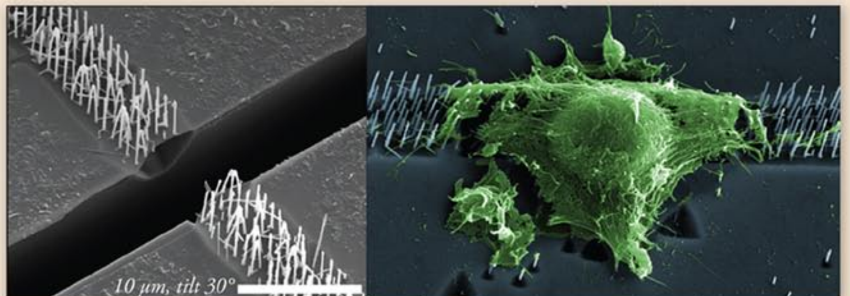
Life sciences

Research in the field of life sciences includes nanobiophysics and nanosafety.

Biosensors (nanowire electrodes) for detecting interactions with nerve cells.



An example of a *lab on a chip* used here to sort particles. The figure shows a so-called *bumper array*, which sorts particles according to size and shape based on the path they take through the device.



Hollow nanowires for the injection of cells.