ANU Centre for Science and Engineering of Materials

Materials Monthly

Making materials matter *June 2002*

Of BECs and Atom Lasers

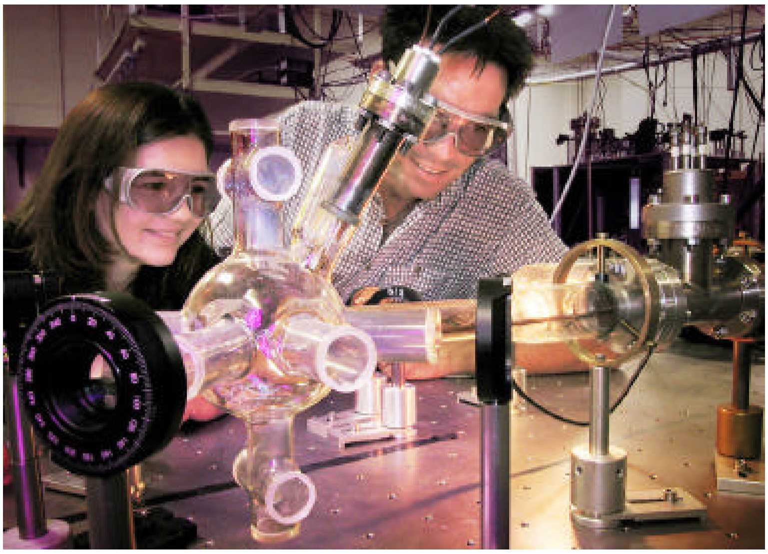
In 1995, a strange new threshold was crossed: atoms were cooled to such an extent that a new form of matter was created. It was known as a Bose-Einstein Condensate, a state of matter in which the waveforms of the super-cooled atoms overlap each other and fall into the same quantum state. The breakthrough was of such fundamental importance that it led to a swathe of Nobel Prizes. (see the BECs box on page 2)

Now the race is on to build applications using the novel characteristics of BECs and the first device that scientists are aiming for is an atom laser. Researchers at ANU's Department of Physics are already working on some exciting designs that could lead to some major breakthroughs in the field.

Atom lasers produce highly controlled beams of atoms with desirable properties analogous to the light beams produced by optical lasers. To understand the connection between a BEC and a laser, consider this: a BEC is to ordinary matter what laser light is to the light from a light bulb. That is, a sample of ordinary atoms (viewed as a quantum wave phenomenon) consists of a collection of unrelated waves, just as the light waves radiated by the randomly firing atoms in the filament of a light bulb are unrelated. In contrast, the atom waves in a BEC are related and therefore constitute a form of coherent matter, just as the light waves in a laser beam are part of a single coherent quantum state.

Atom laser devices simply extract beams or pulses of coherent atoms from a BEC.

Creating a BEC is a tricky and technologically sophisticated process; however, it's a method that's now relatively well understood and has been mastered in a handful of labs around the world. Building an atom laser based on BECs has also been achieved in several labs but controlling the resulting beam of coherent atoms has yet to be mastered sufficiently to enable the laser to be truly useful.



▲▲ Building BECs. Jessica Lye and Cameron Fletcher are two of the researchers working with John Close to build an atom laser that will harness the unique properties of BECs.

In Australia, the first and only lab that has mastered the creation of BECs can be found in ANU's Department of Physics. A small team under the supervision of Dr John Close spent many hours testing, tinkering and assembling the many pieces of apparatus needed to drop the temperature of matter down to only 100 billionths of a degree above absolute zero (-273 degrees Celsius).

The technique involves collecting a diffuse

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Of BECs and Atom Lasers

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gas of cool rubidium atoms in a magnetic field. Lasers slow down the rubidium atoms further, while faster (hotter) atoms are allowed to escape. What remains is a pool of super-cooled atoms that eventually collapse in on each other forming a 'super atom' or a BEC that acts like a single atom but is composed of millions of atoms.

An atom laser results by simply releasing the trapped atoms but the challenge is now to control that beam of atoms. John's lab is currently putting together several designs for a tuneable atom laser. Specifically, what the researchers are attempting to build is a technique that will tune the beam of atoms, and a device that will provide feedback so that the beam can be constantly modified and controlled. The tuning knob will probably involve modifying the magnetic field that contains the BEC.

The feedback device will involve designing a system analogous to the photodiode that provides feedback to a conventional light laser system. However, rather than being a direct feedback system, it's believed the atom laser may required a two step system in which the atom beam first interacts with a laser beam which then strikes a photodiode which then provides a feedback signal to the atom laser.

It's still early days however the Department of Physics possesses a suite of skills that give it real advantages in the development of an atom laser. Indeed, even though it's a small department compared with some of the large institutions in the US working on this problem, the achievements to date by the Physics Department puts it up there with the heavy hitters and gives Australia a real head start in the development of an atom laser.

And what's a atom laser good for? It difficult to give a definitive answer. The science is just so new. However, its believed atom lasers will provide greatly improved sources of atoms for measuring time, gravitational acceleration, and rotation and will lie at the heart of a vast range of devices and applications. Potentially atom lasers can also be manipulated to create sophisticated nanostructures or serve as integral components transmitting information in quantum computers.

"Forty years ago, when the optical laser was in its early stages of development, no one could have envisaged the profound impact it would have on our lives," says John. "The optical laser changed forever the way we work and communicate, and has revolutionised measurement in physics and industry.

"Given the unique properties of atom lasers, I think it'd be safe to say they while we don't know where atom lasers will take us over the coming decades, it's sure to be somewhere exciting."

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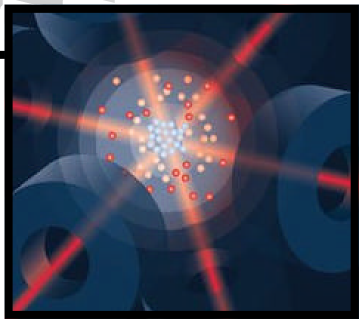


BECs

Not just a new material, it's a new state of matter

Some materials you stumble on, for example high temperature superconductors and buckyballs. You attempt to explain their behaviour afterwards.

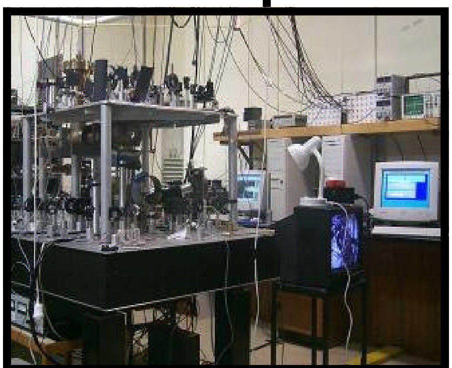
Others are predicted by theory first but it takes a while to come up with the technology to create them. Bose-Einstein Condensates are definitely part of this second group.

They were predicted by Satyendra Nath Bose and Albert Einstein back in the 1920s when quantum mechanics was still getting off the ground. Their equations indicated that if you could cool atoms sufficiently that their wavelength would exceed the inter-particle spacing and the atoms would begin to overlap. In terms of quantum mechanics the atoms would become indistinguishable and would, in effect, enter into a single quantum state. The notion seemed so bizarre that Einstein wondered whether such a state of matter could really exist. In honour of their work, this new state of matter was named a Bose-Einstein Condensate or BEC.

It took over 70 years to develop the techniques that would allow matter to be cooled down sufficiently but in 1995 BECs were created in two labs in the USA. Not only had a new material been discovered, but an entirely new state of matter had been created.

BECs aren't like the solids, liquids and gases. They are not vaporous, not hard, not fluid. Indeed, there are no ordinary words to describe them because they come from another world -- the world of quantum mechanics, where objects behave as both particles and waves, and matter can be in two places at once. (Quantum mechanics describes the rules of light and matter on atomic scales.)

See page 6 for more information on BECs and atom lasers.



◀◀ The BEC apparatus in the Dept. of Phys-

Words of substance

"It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow." -
Robert Goddard

CM300 TEM

Microscopy, analysis & diffraction with transmitted electrons

The CM300 transmission electron microscope (TEM) operated through the ANU Electron Microscope Unit is the most recent in a line of medium-voltage TEMs used for research around ANU's campus since the mid 1970's. The CM300 is normally operated using electrons that have been accelerated by 300,000 volts, and travel at over 77% of the speed of light. The equipment was manufactured in the Netherlands by Philips Electron Optics (since taken over by FEI) and installed at ANU in 1999. The facility is run in the Research School of Earth Sciences on behalf of the Electron Microscope Unit.

▲▲ The CM300 TEM

Features

▷Resolution of images is routinely 0.23 nm, though crystalline lattices as small as 0.14 can be resolved.

▷Useable magnification range between 5,000 & 990,000 x.

▷Eight electromagnetic lenses in the illumination and imaging optics.

▷Conventional electron gun - LaB6 or W source

▷Continuous control of accelerating voltage between 50 and 300 kV

▷All lenses and beam tilts driven under computer control, allowing fast recall of previous alignments, including stigmation corrections.

▷5-axis motor driven specimen stage for precise and versatile translation and tilting, again allowing recall of positions and orientations

▷Large specimen tilt angle of ± 60 degrees

▷Specimen holders for additional 'second' tilt, in double-tilt or tilt-rotate geometry. One holder allows cooling of specimen to 'liquid-nitrogen' temperature

▷Accurate on-line measurement function for image and diffraction space.

▷EDAX X-ray detector with high solid angle of collection which retracts to avoid damage from high energy electrons. It has a thin window for collecting X-rays of low energy (for elements as low as Boron in atomic number) as the basis for chemical analysis.

▷Beams as small as 3 nm can be generated for micro-diffraction and micro-analysis

▷Wide range of beam convergence angle for electron diffraction patterns

▷Calibrated images and diffraction patterns are recorded on film or through a 1 Mbyte Gatan CCD camera

▷Via the CCD camera, on-line beam alignments and image corrections are possible either in fully automated or, more reliably, in an operator-assisted mode

▷Montage routines, coupled to the image shifting features of the TEM, allow digital images much larger than 1Mbyte to be created.

▷Image enhancement and analysis of digital images on-line.

Specimen preparation

Images and diffraction patterns in TEM are produced using electrons transmitted through the specimen, so good samples have to be exceptionally thin and stable under irradiation by high energy electrons. It is a major challenge to produce thin, pristine specimens from larger solid objects, a task made considerably easier by variety of specimen preparation equipment available on campus.

Usage

The CM300 is a most versatile instrument. It's used to study an impressive range of materials which are the focus of different research around campus. The principal users (who grouped together with the EMU to obtain RIEF and Major Equipment Funding for CM300 purchase) include RSPhysSE, RSES, RSC and Geology Department. Projects range from electronic materials (ion implanted semiconductors like Si, SiC and GaAs) through nanomaterials (BN and C nanotubes - see Materials Monthly May 2001) through rocks and minerals (grain boundaries in synthetic olivine polycrystals) to sea-urchin skeletons and fast-ion-conducting perovskites.

More information:

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John Fitzgerald at the controls. For examples of images taken by the CM300, see pages 5 & 6. ▼▼

Opportunities

Microscopy: Imaging and Analysis

The ANU Electron Microscopy Unit (ANU EMU) is now calling for enrolments in their Microscopy Imaging and Analysis courses for 2002.

Every year the ANU EMU runs a series of 1-3 day workshops. Postgraduate research students using electron microscopy (imaging or analysis) in their projects are strongly advised to attend, but anyone else who wants to improve their knowledge of theory and technique is welcome. For series I workshops there is no charge for ANU staff and students, however for anyone outside of ANU there is a $100 fee per session.

Course information on the ANU EMU website will be updated shortly, with more details.
There are two groups of sessions (all start at 9am).

Series I covers:

1. Understanding & Manipulating Images (from acquisition to publication)
When: Provisionally Tuesday 26th/Wednesday 27th June.
Where: Robertson Seminar Room, RSBS
Content: Principles of digital image acquisition with emphasis on light and electron microscopes, processing the image to reduce noise or emphasise particular features, introduction to some commonly available measurement and image processing programs, things to consider when printing.

2. Introduction to SEM
When: Tuesday July 2nd
Where: Rm 1128 New Extension Seminar Room, RSBS
Content: An intro to EM columns and the principles and practice of Scanning EM. The type of applications discussed (materials, biological, cryo) may change from year to year depending on the background of the participants.

3. Introduction to TEM
When:Tuesday 9th July
Where: Robertson Seminar Room, RSBS
Content: Continuation of introduction EM columns, and to the principles and practice of Transmission EM operation. Note that many of the basics common to both SEMs and TEMs will be covered only once in sessions 2 and 3.

Attendence at Series I, or an agreed equivalent is a prerequisite for Series II sessions which may be organised later in the year depending on demand.

If you would like to attend any the following Series II courses in 2002, please email Sally Stowe and let her know.

Possible Series II sessions:

4. TEM II - basic theory and practice for Diffraction, Darkfield and Convergent Beam applications.
5. X-ray Analysis - EDXA and WDS on the SEM and electron probe.
6. Biological TEM
7. Light microscopy techniques
8. Cryotechniques - High Pressure and other freezing techniques, SEM and TEM cold stage work.

For more information or to make a booking, please contact Dr Sally Stowe, Facility Coordinator.
Email: stowe@rsbs.anu.edu.au

Conferences / Seminars

◄✧► **M&M 2002** — **4-8 August**
Microscopy and Microanalysis 2002
Quebec City, Canada
http://www.microscopy.com/MSAMeetings/MMMeeting.html

◄✧► **Photonic Crystals Down Under** — **18-24 August**
first conference on photonic crystals in the Southern Hemisphere
Canberra
http://wwwrsphysse.anu.edu.au/nonlinear/meeting/

◄✧► **ICEM 15** — **1-6 September**
15th International Congress on Electron Microscopy.
Durban, South Africa
http://www.icem15.com/

◄✧► **11th SolarPaces** — **4-6 September**
International Symposium on Concentrated Solar Power and Chemical Technologies
Zurich, Switzerland
http://www.solarpaces2002.ch/

◄✧► **Seminar: Conservation approaches to excavated metal objects** — **18 September**
Canberra Archaeological Society Lecture: David Thurrowgood (Nat. Mus of Aust)
7.30 pm, Manning Clark Lecture Lt 6, Manning Clarke Centre, ANU.
http://car.anu.edu.au/Cas.html

◄✧► **APSEC 2002** — **4-6 December**
9th Asia Pacific Software Engineering Conference
Gold Coast, Qld
http://www.acs.org.au/pd/acs_conferences/cfp2.doc

New: 'Earth Materials

The importance of materials research in the earth sciences was reflected in the recent reorganisation of research activities within the non-departmental structure of the Research School of Earth Sciences. The School's research activities have been grouped into four broad areas one of which is 'Earth Materials' - encompassing the activities of the Petrochemistry and Experimental Petrology and the Petrophysics Research Groups. Former CSEM Director Dr. Ian Jackson has been appointed to a two-year term as Coordinator, Earth Materials with a range of responsibilities delegated by the Director, RSES including discretionary research funding, student recruitment and training , and broad supervision of academic and general staff. Day-to-day responsibilites for the operation of particular facilities and supervision of associated staff will remain delocalised.

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Why study chemistry at uni?

The Research School of Chemistry is playing a leading role in an innovative outreach program called UniChe. The program aims to strengthen the relationship between universities and the Australian chemical industry, and to promote chemistry as a valuable and fulfilling course of study at university. Partners in the program are the ANU, Newcastle Uni, Melbourne Uni, and Australia's largest chemical company, ORICA.

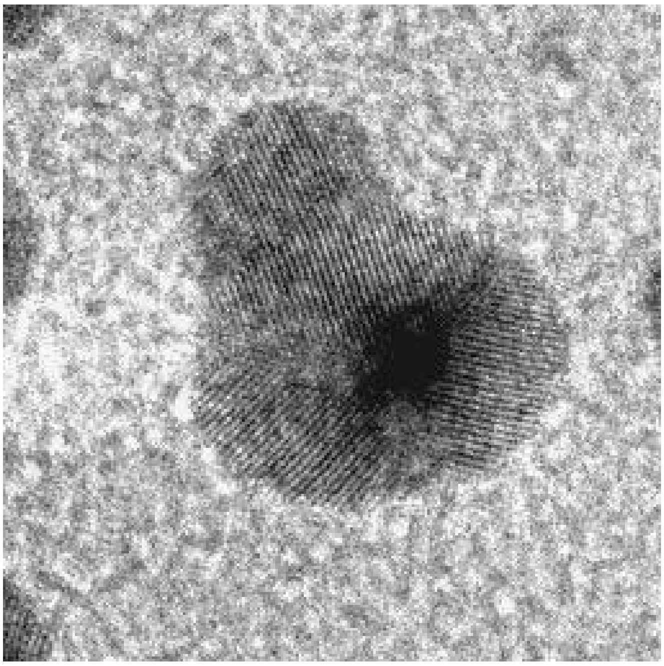
The ANU involvement is headed by Prof John White and Dr Philip Reynolds, and includes a school outreach scheme. The outreach program is being coordinated by Leharne Fountain, a Master of Science student at the Centre for the Public Awareness of Science (ANU).

The outreach team is currently visiting Year 11 and 12 students in the ACT and surrounding NSW. In a two-pronged approach, school visits involve a short session led by Leharne addressing the relevance of chemistry and career options in chemistry. This is followed by an informal lecture given by a volunteer member of staff from the RSC.

Leharne's approach is aimed at encouraging the students to think about chemistry in every day life, and our dependence on the products of chemistry. The many applications of chemistry are discussed, and the range of careers that chemistry can lead to are highlighted. Some of the less obvious ones include forensic science, science communication, and environmental science. The team hopes the outreach program will encourage some of the students to take up chemistry at the ANU in the future.

The UNICHE Project

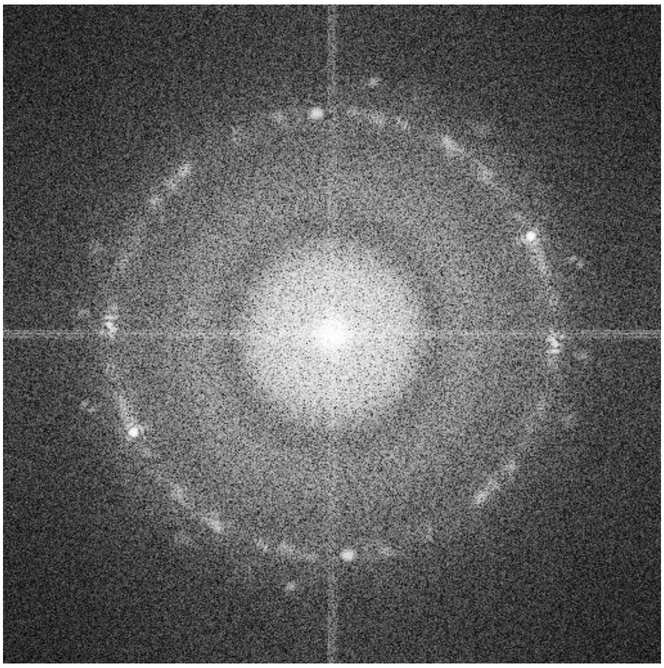
Materials Grab Bag



Transforming Gold

▲▲Pictured above is a tiny particle of gold some 10 nm in diameter on a background carbon film. The gold lattices (spacing 0.23 nm) reveal the particle is made from 3 smaller crystalline domains of different orientation. The image was captured by the CM300 Transmission Electron Microscope (featured on page 3).

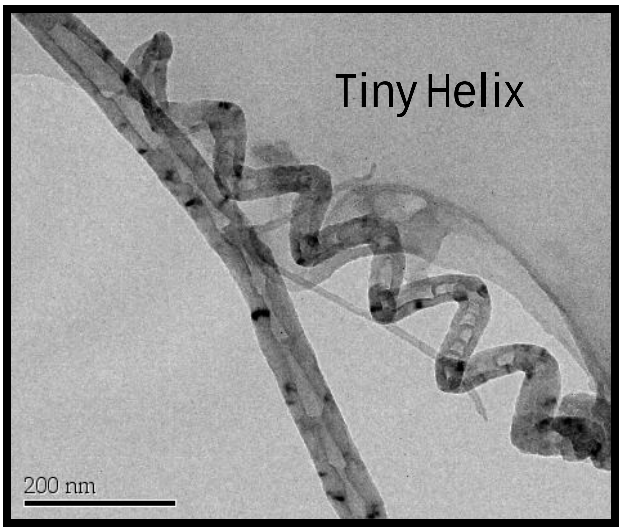
Below is an on-line, fast-fourier transform of the gold particle. This transform clearly shows the 0.23 nm lattices well resolved (the outer bright ring) but also the circular symmetry of the inner rings (coming from the background carbon film). The transform was used to align and stigmate the electron microscope column before the image was taken. Image analysis such as this is one of the many features of the CM300. ▼▼



MM webspotting:

Atom Lasers &BECs

- ♦ **BECs at ANU**
  http://www.anu.edu.au/Physics/ANUBEC/homeframe.html
- ♦ **A rudimentary atom laser**
  http://www.aip.org/physnews/preview/1997/alaser/
- ♦ **Atom lasers: the next generation**
  http://www.aip.org/physnews/graphics/html/alaser99.htm
- ♦ **BECs: a new form of matter**
  http://science.nasa.gov/headlines/y2002/20mar_newmatter.htm
- ♦ **Atom laser pictures**
  http://cua.mit.edu/ketterle_group/Projects_1997/Atom_laser_pics/Atom_laser_pics.htm



Corkscrews don't come much smaller than this - it would need to be100,000 times larger to be any use in opening your next bottle of Penfolds! It's actually a helical Boron Nitride nanotube grown at the ANU by Ying Chen and photographed in the CM300 transmission electron microscope. The helical tube 40nm in diameter coils on a 150nm scale and rests on the edge of a carbon film alongside two straighter nanotubes, one 60nm diameter and the other a miniscule 10nm diameter! (For more info on the CM300 TEM, see page 3.) ▲▲

CSEM

ANU Centre for Science & Engineering of Materials

Faculties
Department of Chemistry
Depart of Engineering
Department of Forestry
Department of Geology
Department of Physics

Institute of the Arts
Materials Workshops

Institute of Advanced Studies
Research School of Biological Sciences
Research School of Chemistry
Research School of Earth Sciences
John Curtin School of Medical Research
Research School of Physical Sciences & Engineering

Materials Monthly

Volume III, Issue 6

June 2002

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Please let us know if you wish to be added to our electronic or postal mailing lists.

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