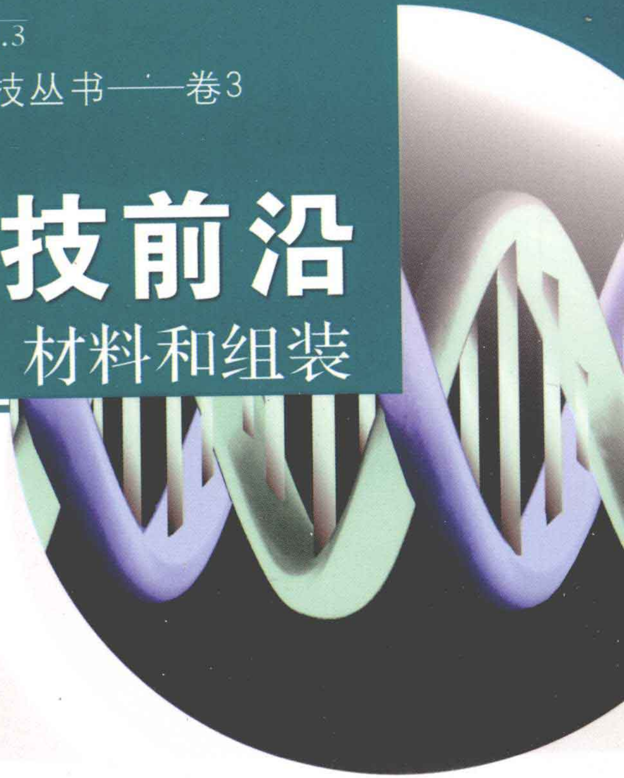
Royal Society Series on Advances in Science - Vol.3

英国皇家学会前沿科技丛书——卷3

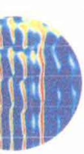
# 纳米科技前沿

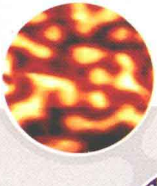
## ——电子学、材料和组装

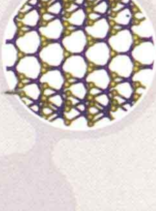


# Advances in Nanoengineering

## Electronics, Materials and Assembly





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# 纳米科技前沿

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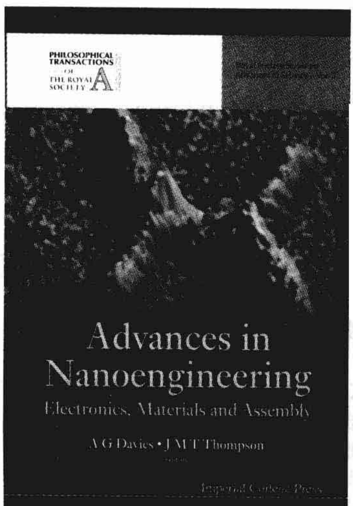
J. M. T. 汤普森　（剑桥大学）

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# 关于《英国皇家学会前沿科技丛书》的一点说明

这套《英国皇家学会前沿科技丛书》（Royal Society Series on Advances in Science）共三卷，主编是英国剑桥大学教授、英国皇家学会会员 J. M. T. 汤普森（J. M. T. Thompson）。三卷依次为：

卷 1：《天文学前沿——从大爆炸到太阳系》；
卷 2：《地球科学前沿——从地震到全球变暖》；
卷 3：《纳米科技前沿——电子学、材料和组装》。

这套丛书的内容基本上是针对这三个学科当前的进展情况而写的，无论是从内容还是从出版时间来看都是相当新的，属于这三个学科的前沿。

这三卷是由多名作者合写而成的，每人就其所从事的研究领域各写自己的专题。因此，内容不仅丰富、真实可靠，而且极具权威性，不是什么“二手货”。可以说，书的专业学术分量充足，“含金量足够”。每章的内容基本上都是从问题的提出开始，对历史沿革和发展经过、目前研究的主要内容、可能的技术应用以及未来的发展动向都有所涉及、描述和讨论，对于从事相关领域的研究人员了解该领域的现状和发展动向很有帮助。对于初入门或正想进入这些研究领域的青年学者来说，这套书不仅可以丰富他们的专业知识、扩展他们的视野，更可以为他们选择适合于自己兴趣的研究方向提供帮助。而对于大学生和那些对这些领域的知识和发展方向有兴趣的一般读者来说，阅读这些书，既可以增进他们的科学知识，也可以助其了解这些领域的发展方向。所以说，为我国读者引进这些书，无疑大有裨益。

这三卷中各章的作者基本上是英国从事一线研究的青年科学家。对这些青年科学家，由主编汤普森教授在丛书卷1的前言中作了简单说明：青年科学家是指那些博士后研究经历不超过十年，外加在英国大学中有研究员身份，从事过三年本学科研究的研究人员。这些青年科学家虽然没有老科学家那么经验丰富，但是更加朝气蓬勃，在学术发展上更具雄心，在探引新的发展方向上或许更为敏锐，因而写出的书更具有特色。

关于这套丛书的写法，虽然在其前言中说到，作者们注意了语言的通俗性，也没有使用大量的数学推导和公式，附图也比较多，但基本上是通用学术论文的写法，且差不多每篇末尾都列出了相当多的参考文献。这对于想更多、更深地了解该课题（领域）的人来说，无疑大有帮助。由于每卷都是由多个作者分章写成，因此，并没有像单个作者那样，构思时着重全书前后贯通，写作时注意一气呵成，多少会感到有些分散。

这套丛书涉及的每个学科领域的内容都很广泛，特别是像纳米科技，要想在一本书中都囊括到，是很难的。这一点在《纳米科技前沿——电子学、材料和组装》的前言中特别作了说明。但是，纳米材料可能的毒性以及纳米科技所带来的社会伦理问题非常重要，不可避之，而书中并未专题涉及，当是美中不足之处。

张邦维

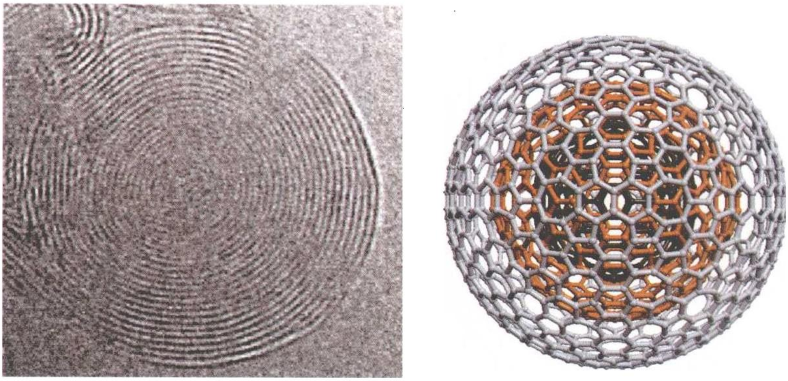
2011年8月1日于岳麓山下

# PREFACE

Although researchers began to use the prefix "nano" more than thirty years ago, it is only in the last ten years that its use has spread to virtually every field of science, technology and medicine. Today it is used as much for fashion as it is for scientific classification, but the blossoming of interest nevertheless reflects a genuine explosion in the useful application of nano-techniques and nanomaterials to both science and technology. We have reached the point where it is possible to manipulate materials at the molecular and atomic level and create genuinely new materials and processes that are tuned for particular applications. Examples have emerged in fields as disparate as novel semiconductors for nanoelectronics and medicines for the treatment of hereditory illnesses. Capabilities are emerging in nanoscience and nanotechnology that could not have been imagined two decades ago and this book provides an invaluable underpinning for those genuinely interested in understanding their limits and capabilities so that they can apply them to the advancement of science and engineering.

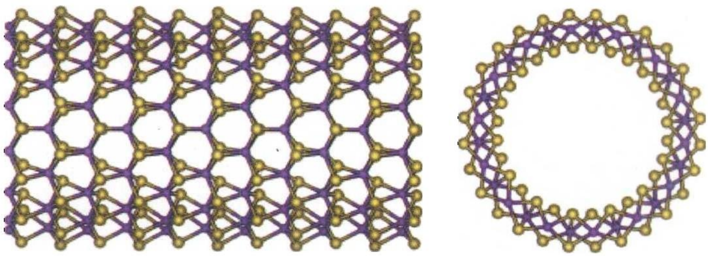
When the prefix "nano" was first used in the 1970s, it genuinely referred to structures with dimensions that approached a nanometer or at least a few nanometers, and distinguished them from microstructures, but as its use spread, the definition was loosened to embrace structures up to 100 nanometer and that is where it has settled. It is important to preserve it at this level if the classification is to remain of value. This volume concentrates on the science and technology that underpins the genuine advances that have been made in manipulation and examination at dimensions below 100 nanometers. Starting with a chapter on carbon and its various molecular configurations it contains chapters written by experts on both man-made and naturally occurring structures, on nanodevices with potential application to information and communication technologies, and on the advanced analytical and microscopical techniques that have been developed to examine and assess these incredible small artifacts. There are chapters on molecular self-assembly and tunnel transport through proteins showing how science and technology can now operate at a level that probes the internal mechanisms of life itself. The nanoworld is so wide and diverse that no single volume is going to give comprehensive coverage of worldwide activity but this book covers as much as any and will long be useful as a reference to those entering the field or interested in its capabilities.

Lord Broers FREng FRS
Chairman, House of Lords Science and Technology Select Committee
Past President, Royal Academy of Engineering

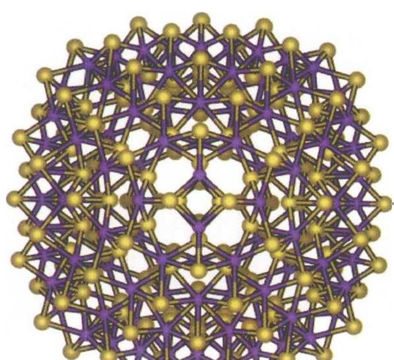


(a) (b)

(a) Spherical carbon onion produced in a TEM at 700°C and (b) model proposed by Terrones and Terrones for spherical carbon onions based on the introduction of additional heptagonal and pentagonal carbon rings (Terrones and Terrones, 1996).

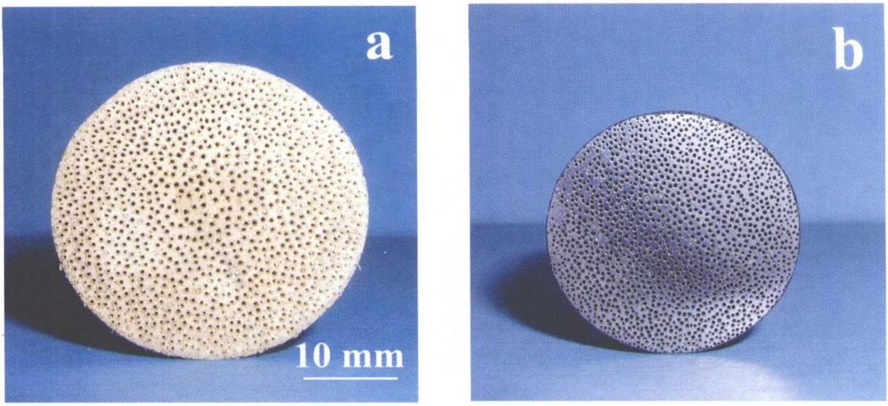


(a)

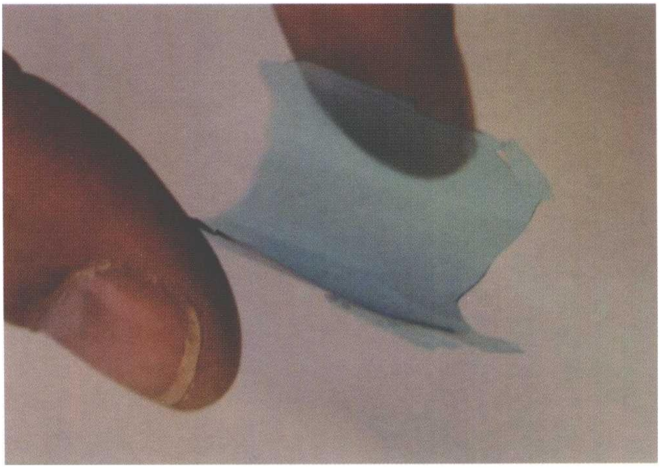


(b)

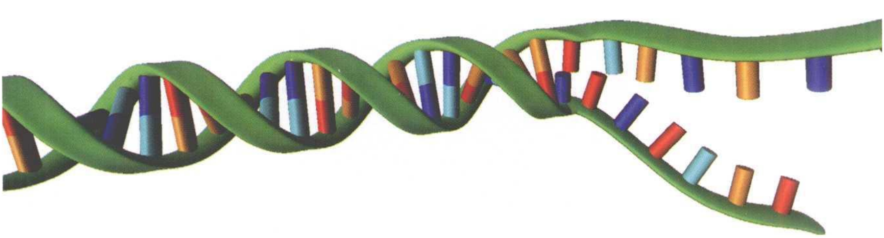
(a) Molybdenum sulphide zigzag-type nanotube. (b) Molybdenum sulphide octahedral cage.



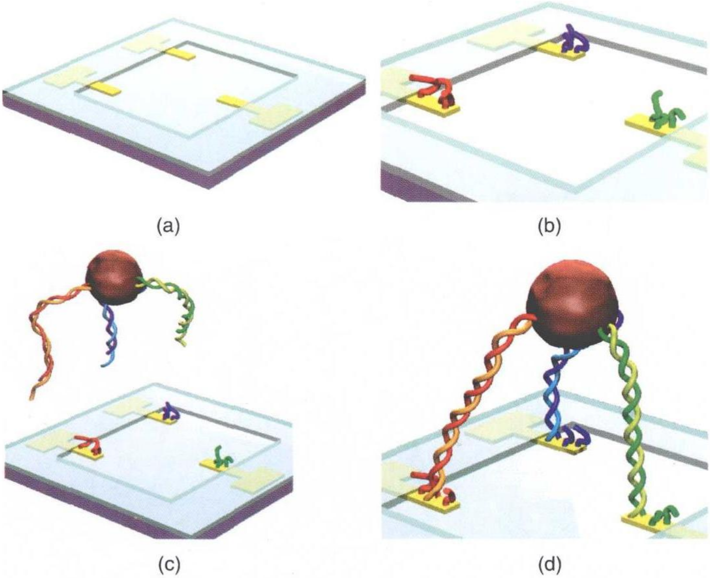

Images of (a) rattan wood and (b) rattan-derived Si–SiC zeolitic bioceramic.



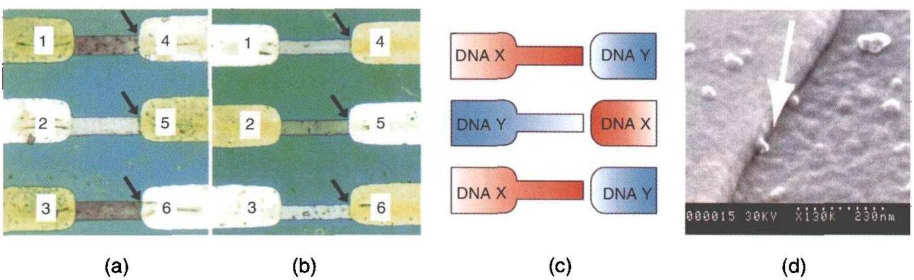
A thin, clear blue film of chitosan/Y124 superconductor precursor.



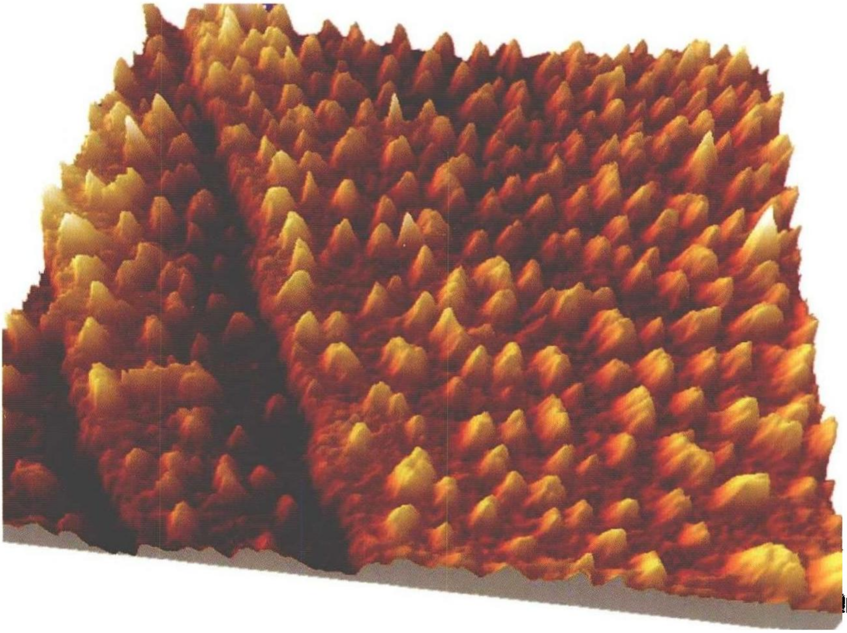
Schematic illustration of double- and single-stranded DNA. The backbone is shown as a green ribbon to which the individual bases are attached. The four different DNA bases are indicated by different colors.



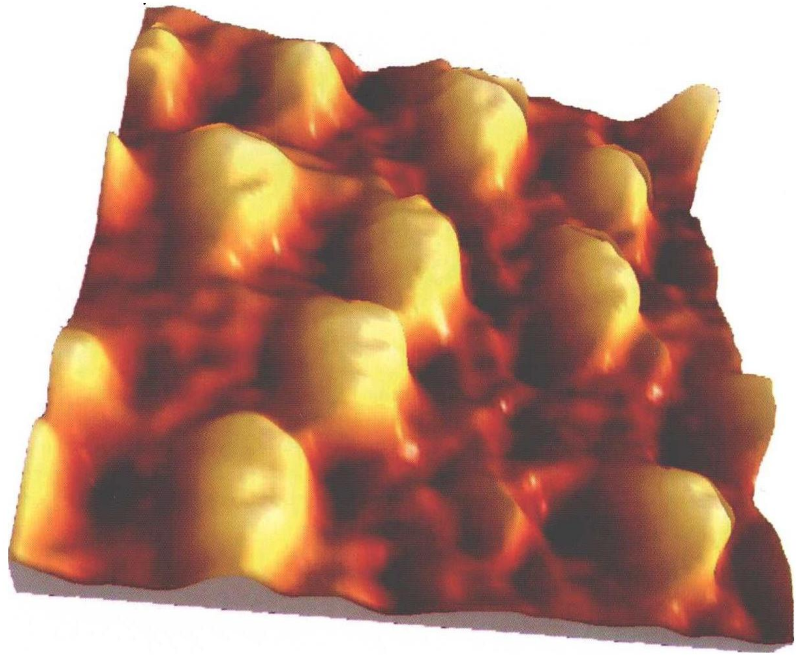
Nanoscale assembly exploiting the molecular self-organization properties of DNA. The three electrodes are functionalized with different single-stranded DNA molecules (b) and the three arms of the molecular complex with the three corresponding complementary DNA oligonucleotides (c). The molecular complex is then assembled onto the device using the self-organizing properties of DNA (d).



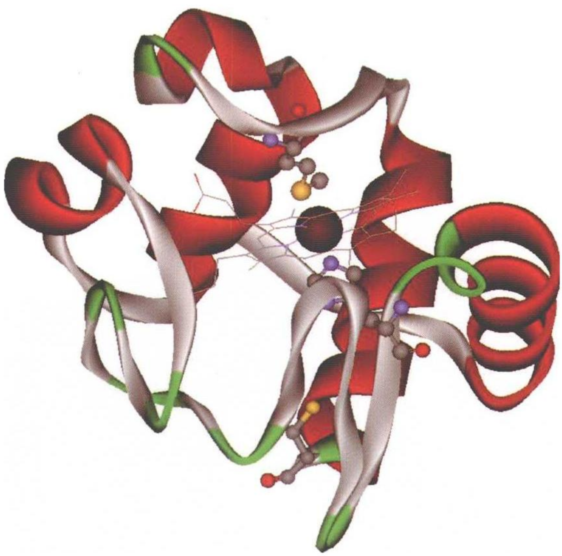

((a), (b)) Electrode arrays with nanoscale gaps separating opposing electrodes (indicated by black arrows). Electrodes 1, 3, and 5 are coated with oligonucleotides **X** and electrodes 2, 4, and 6 with oligonucleotides **Y**. The darker color of the electrodes (a) 1, 3, and 5 indicates the presence of surface-bound oligonucleotides **X**, and (b) of the electrodes 2, 4, and 6 the presence of oligonucleotides **Y**. (c) Schematic of the electrode array. (d) SEM image of the area between two opposing electrodes. The white arrow indicates the gap which appears as a dark line. Reprinted with permission from Ref. 65. Copyright (2003) American Chemical Society.



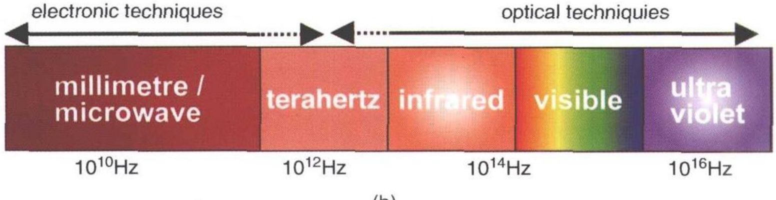
Tunneling image of an array of self-assembled blue copper proteins on an Au[III] electrode surface. The image (approximately 140 nm × 140 nm) was acquired under a water-glycerol mix at room temperature at a tunneling set point of 75 pA (200 mV). These robust molecular layers are generated by using the strong thiol–gold-bonding interactions attainable by adding, genetically, cysteine amino acids to the surface of the metalloprotein. The surface density of these layers can be measured by voltammetric methods to be 1–2 × $10^{13}$ molecules/$cm^2$.



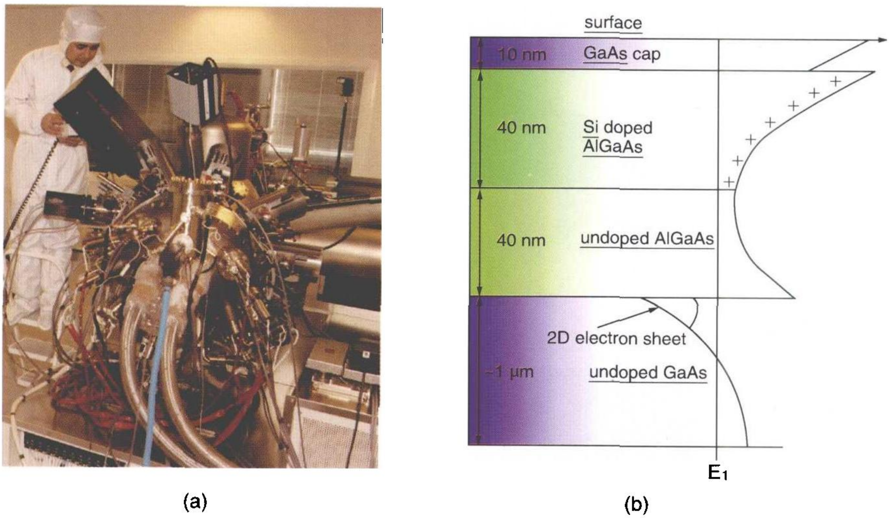
*In situ* electrochemical STM (10-mM phosphate-buffered saline, pH 7.5; − 0.3 V, 300 pA) of yeast iso-cytochrome *c* molecules adsorbed onto a bare gold electrode surface. Each molecule is approximately 3 nm in diameter and contains one redox-addressable heem group. The role played by the latter in mediating tunneling, under appropriate experimental conditions, can be utilized in "gating" conductance electrochemically (Fig. 3).



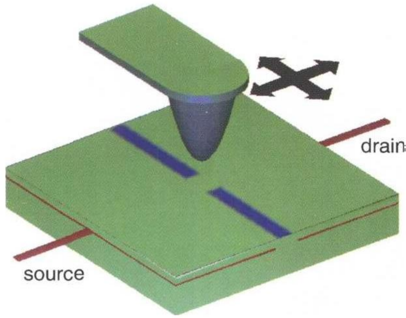
(a) Structure of yeast iso-cytochrome $c$ (pdb IC:1YCC, Ref. 32). The $\sim 3.5$-nm diameter, 13-kDa, protein has a heem group which is electrochemically switchable. This particular form of cytochrome $c$ has a solvent-exposed cysteine residue which may usefully be utilized in anchoring the molecule to gold- or sulphur-presenting surfaces. The distance between the thiol and the buried edge of the heem is approximately 1.6 nm.



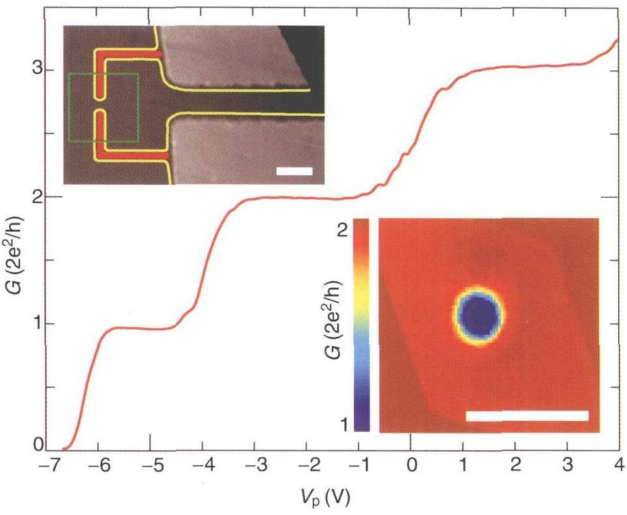

Two limits for modern electronic systems. (a) The size of the system which contains electrons; from left to right in order of increasing size: simulation of electron density around a single atom, carbon monoxide atoms arranged on a platinum surface, a multiwalled carbon nanotube, a semiconductor structure fabricated using electron beam lithography, and a conventional electronic circuit formed using optical lithography. (b) The frequency of operation; the upper frequency range for electronic circuits lies in the low terahertz range, where electronic concepts merge with photonics.




(a) Photograph of a typical MBE machine, used to grow atomic layers of semiconductor material. (b) Schematic of MBE-grown GaAs/AlGaAs heterostructure wafer structure, and its associated energy profile as a function of depth into the wafer. Electrons from the $n$-type donar layer migrate to the interface between the undoped AlGaAs and GaAs substrate interface, where confinement causes them to form a 2D electron sheet.

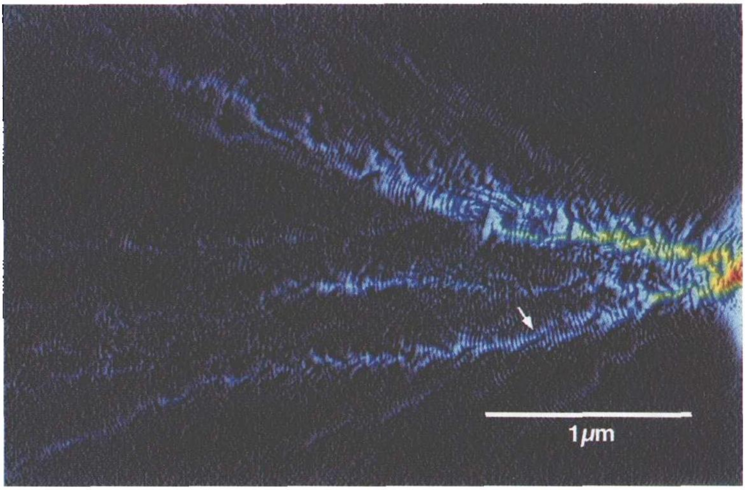



(a)

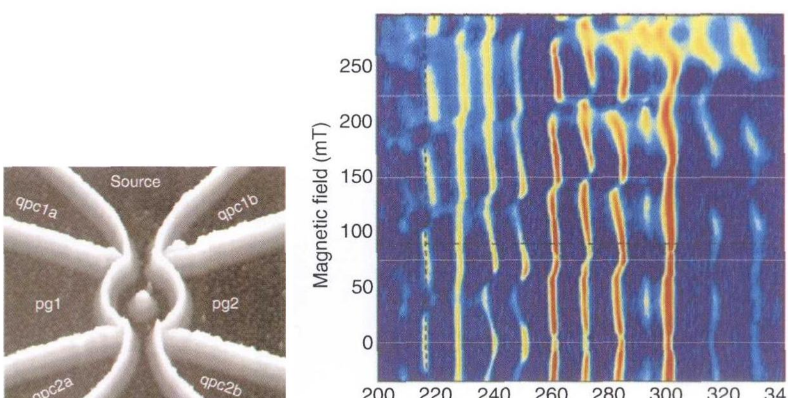



(b)

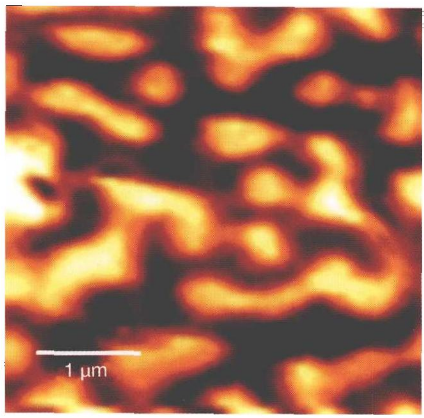
(a) Experimental setup for the study of a quantum wire fabricated by EEL. Negative surface charge is shown in blue. The quantum wire is defined in the subsurface 2DEG, below the gap in the line of surface charge. (b) Plot of device conductance as a function of tip bias and therefore wire width. Plateaus are observed at integer multiples of $2e^2/h$. Upper inset: AFM image of surface electrodes superimposed with surface charge and depletion outlined in yellow. Lower inset: SGM image of the quantum wire made over the region indicated in the upper inset. Scale bar 1 $\mu$m. Parts of this figure were originally published in Ref. 16.



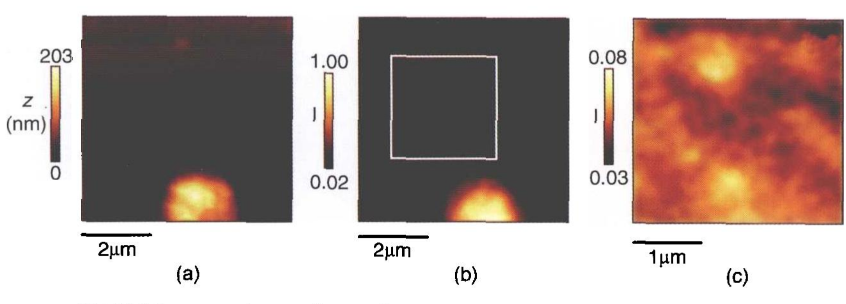

SGM image made over a region to the left of a quantum wire. The arrow indicates a cusp where electron interference is regenerated. Scale bar 1 $\mu$m. Figure originally published in Ref. 21.




(a) AFM image of a quantum ring fabricated using LAO. The in-plane gates defined by LAO (qpc1a, qpc1b, qpc2a, qpc2b, pg1, and pg2) are used to tune the size of the quantum wires and the quantum ring. (b) Plot of device conductance as a function of the size of the ring (voltage to pg1 and pg2) and the magnetic field. Coulomb blockade oscillations are seen along the $x$-axis, and AB-like oscillations along the $y$-axis. Figure originally published in Ref. 29.




An image of the fluorescence emitted from a blend of two light-emitting polymers, measured using aperture-SNOM. By exciting with carefully chosen wavelengths of light, only one absorbs and then re-emits light.




SNOM images of a conjugated polymer blend film containing 10% by weight F8BT and 90% by weight PFB. Intensity ($I$) is in arbitrary units, and height ($z$) is in nm. (a) Topographic image. (b) The corresponding fluorescence image for (a). The topographic and fluorescence images were measured simultaneously. (c) An enlarged fluorescence image, taken from the white box shown in (b); the intensity scale is the same as for (b).