momentum created was large enough to explain the insect's forward motion, whereas the contribution of the capillary waves was much too small. So, despite their small size, the legs of water striders are analogous to the oars of a rowing-boat, which also move forwards by sending a series of vortices backwards through the fluid. This more accurate understanding of water striders fits well with the emerging picture of animal locomotion. Through their use of vortices, water striders share general features with animals flying above and swimming below them. ■

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Nanotechnology

A barrier falls

J. Tersoff

Electronic devices based on carbon nanotubes have a bright future — even more so now that a way has been found to eliminate the 'Schottky barrier' that hinders the injection of electrons into them.

Since the days of vacuum tubes, a key problem in the use of electronic devices has been getting electrons into the device from a metal connecting wire. Even the tiny transistors now being made from semiconducting carbon nanotubes share this classic problem: their performance is limited by an energy barrier that hinders electrons entering the nanotube. But now it seems that this barrier has fallen. In a paper on page 654 of this issue, Javey *et al.*[1] report the fabrication of nanotube transistors with improved performance, achieved by reducing or eliminating the barrier that electrons must cross from the metal wire into the semiconducting nanotube.

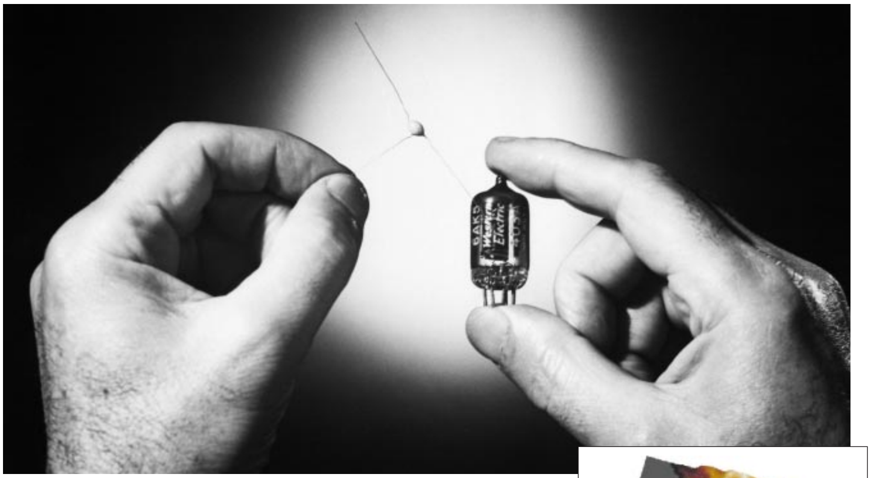
To be sure, nanotube transistors are already performing impressively in device applications[2]. But eliminating the barrier to electron flow is an important advance that will open the way for further improvements. The key, according to Javey *et al.*, is to use the correct combination of metal wire and nanotube. With little or no barrier to overcome, electrons have a good chance of shooting through the nanoscale device ballistically, without being slowed by scattering. In this way, much higher currents and lower resistances are achieved than ever before — within a factor of two of the ultimate quantum limit for such a device[1].

The struggle to overcome energy barriers in electronic devices has a long history. In the venerable vacuum tube (Fig. 1), electrons face a large energy barrier to moving from the metal wire into the vacuum. The energy to overcome this vacuum barrier is provided by heating the wire until it glows brightly — an approach with obvious limitations. A similar problem plagued early devices made from familiar semiconductors such as silicon. There is an energy barrier, called the 'Schottky barrier', that electrons must overcome to get from a metal wire into the semiconductor. Modern silicon transistors circumvent the problem by replacing the metal wire with a silicon wire that is 'doped' with special impurities so that it can carry current to the device without any Schottky barrier.

Semiconducting nanotubes have the same problem: there is typically a Schottky barrier between the incoming metal wire and the nanotube. Nanotubes can be doped[3–5], and replacing the metal wire with a doped nanotube should also work here, just as it does for silicon[6]. But to form useful contacts in this way would require heavy doping with nanoscale spatial control — a formidable challenge. Instead, nanotube transistors have tended to rely on a geometrical advantage that they have over silicon. Because the tube is almost a one-dimensional wire, an external electric field can penetrate right to the metal–nanotube interface and reshape the barrier. If an appropriate voltage is applied, the Schottky barrier can be made so thin that electrons 'tunnel' quantum-mechanically through it. In this way, good device performance has been achieved despite any barrier[2], and there is room for further improvement by designing devices with this effect in mind[5].

Nevertheless, such tunnelling always entails extra resistance: although an electron may tunnel through the thin Schottky barrier, it also has some probability of being reflected. A device's performance would be substantially improved if the Schottky barrier could be eliminated altogether, but this has not proved possible for silicon and similar semiconductors. It was anticipated that, for nanotubes, the Schottky barriers might be more easily controlled, either because the nanotube itself does not bond chemically to the metal contact, or because the nanoscale geometry makes the bonding less effective in 'pinning' the barrier height[7]. Experimental measurements support this idea[5].

Despite these tantalizing suggestions, there had been no clear demonstration that



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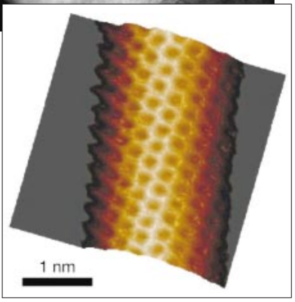

Figure 1 **State of the art. Fifty years ago (when the image above was taken), the vacuum tube that had revolutionized electronics, especially in radio communications, was superseded by the transistor, a new electronic component many times smaller. Since then, transistors have shrunk to microscopic size. Now attention is turning to carbon nanotubes (an example is shown, right, in this scanning-tunnelling-microscope image; reproduced from ref. 8). Nanotubes are little more than a nanometre in diameter, but share a common problem with their electronic predecessors — how best to get electrons into the device. Javey *et al.*[1] have now found a solution.**

barrier control could make a better device — until now. Using palladium for the metal connecting wire and relatively wide-diameter (about 3 nm) nanotubes, Javey *et al.*[1] have achieved this feat, eliminating the Schottky barrier and observing ballistic transmission of electrons through the device. Both choices, of palladium and of wide-diameter nanotubes, raise intriguing and as yet unanswered questions. The authors note that there is no obvious reason why palladium should give a smaller barrier than, say, platinum; palladium is distinguished primarily by its ability to stick well to carbon nanotubes. So why is its electrical behaviour different? Does palladium react chemically with the carbon tube? Does it differ from platinum or gold in barrier height, or in some other way? Can we rule out the existence of a Schottky barrier so thin as to be virtually transparent to electrons[5]? And can the barrier be similarly eliminated in narrower tubes, whose electrical properties are more favourable for practical devices?

In any case, Javey and colleagues' device brings us much closer to the fundamental limits of conductance; it is capable of carrying unprecedented currents at modest voltage. The evidence is compelling that this improvement comes from effectively eliminating the Schottky barrier. And although there is as yet no answer to why the barrier disappears, this work raises hope that control of the Schottky barrier will become integral to future nanotube-device technology. ■

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Atmospheric science

African dust in Florida clouds

Owen B. Toon

Satellites and numerical models now track the intercontinental transport of airborne particles. Better knowledge of cloud physics will be necessary to gauge the effects on clouds and rainfall patterns.

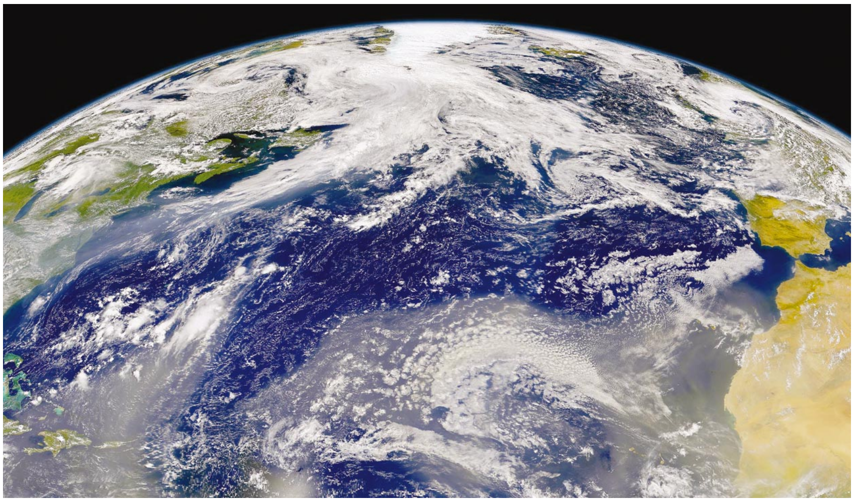
If you live near a desert you expect to get dusty every now and again. Strong winds bounce sand grains across the desert surface, which in turn blast micrometre-sized particles into the air, where they blow downwind and eventually land on you. Desert dust might not seem to be a problem in a lush tropical environment such as Florida, but as our view of Earth has improved it has become clear that dust is blowing everywhere and seeping into everything. As they report in *Geophysical Research Letters*, Sassen *et al.*[1] and DeMott *et al.*[2] show that dust from the Sahara Desert in Africa can have an impact on clouds over Florida (Fig. 1). Sassen[3] previously found that dust from Asia was affecting clouds over the western United States.

Advances in satellite remote sensing and in numerical modelling of aerosol behaviour now make possible the daily production of images and forecasts for the locations of dense dust plumes, as well as of clouds of smoke and sulphates[4]. So it was that in April 2001, awakening to visibly dirty air in Boulder, Colorado, a quick glance at the Internet[4] showed me that local pollution was not to blame, but a dust storm in China a few days earlier. Smoke plumes from far-distant fires are also commonly observed and can now be traced back to their sources, often on the other side of the world.

Intercontinental transport of dust has several implications, some of which have been recognized only recently. Dust scatters and absorbs sunlight, as well as infrared light radiated by the Earth, which alters the radiation budget and is a major factor in studies of climate and climate change[5]. It is difficult to regulate air-pollution standards when they are violated by dust storms occurring halfway around the world[6]. In different contexts, wind-blown dust is a significant source of minerals for oceanic plankton, and it may be a way in which biological debris is transported over intercontinental scales. On a more local scale, a dust storm in Iran caused the collapse of a military venture to rescue the US embassy hostages in 1980, dooming the re-election prospects of President Jimmy Carter, and such storms severely affected operations in the recent conflicts in Afghanistan and Iraq.

It has long been clear that rainfall is the principal mechanism for cleansing the sky of dust, but only recently has the impact of dust on clouds been appreciated[7]. Sassen *et al.*[1] and DeMott *et al.*[2] now show that such effects may be widespread and not restricted to regions near deserts.

Dust may affect clouds in two ways. All water droplets start off by forming on preexisting particles. As the number of particles increases, for instance due to a dust storm, the number of cloud droplets may increase. If there are more cloud droplets, the droplets will be smaller because the mass of condensing water is usually fixed by air motions and ambient humidity. Smaller cloud droplets make for a greater surface area, and hence brighter clouds, a consequence that was the first indirect effect of aerosols on climate to be recognized, and that has been the object of intense study over the past decade. A less well-studied phenomenon is that smaller droplets are also much less likely to collide with each other and create precipitation. Although the net flow of water through the atmosphere may be set by the rate of evaporation from the oceans, the locations of



SEAWIFS PROJECT, NASA/GSFC, ORBIMAGE

Figure 1 **Dust-up. In this image, produced with data from the SeaWiFS satellite, Saharan dust appears as a brownish haze spread across the Atlantic Ocean from Africa to the Caribbean, mingling with various cloud systems along the way. Such cross-Atlantic transport of dust is continually observed by satellites.**