The vacuum tube's comeback

A miniaturised version is set to reclaim its place over the newbie transistor, says s ananthanarayanan

THE vacuum tube valve was the marvel at the turn of the 20th century, making possible the control of electric currents at a very rapid pace and leading to radio communication, improvements in telephony, digital computing and ushering in the electronics revolution. But when the less bulky, low-cost and low-power transistor entered the picture, the vacuum tube got pushed aside and is hardly heard of today. But it had its merits and a miniaturised version that can be integrated in solid state circuits will soon take its place to help transistors cross their own hurdles, according a paper to appear soon in the American Institute of Physics' journal, *Applied Physics Letters*.

While electric cells, currents, magnetic effects, electric motors, the electric bulb, where current passed through metal wires, were making progress in the late 1800s, research looked at passing currents through gasses or through a vacuum. In the early electric discharge tubes, electrons arose at a heated coil and were swept through the tube by the applied voltage. Reversing the voltage stopped the current, because the electrons were generated only at one end. The simple vacuum tube was thus a one-way street for electric currents — a property that ordinary conductors did not have. An improvement was to place an electric barrier between the two ends of the tube, to stop or allow the current to pass. This became a high-speed switch. And then it was seen that minute variations in the barrier charge could cause large changes in the current through the tube. This became a way to amplify a low power varying current, applied at the barrier, into an identical, high power variation in the power passing through the tube.

It thus became possible to pick up very low intensity radio waves in distant antennae or aerials and amplify the signal to audible levels. This was the beginning of radio communication as well as recording and playback. The one-way diode valve, along with the intervening electrode to make it function as a "gate", allowed digital data to be generated, transmitted and decoded. This enabled diverse control devices and also the first digital computers. When the current of electrons in vacuum tubes struck a chemically coated screen, they made the screen glow with light — and this was the beginning of the television screen. As the action of vacuum tubes was fast indeed, very high frequencies were feasible as were the great advances in electronics, thanks to this feature.

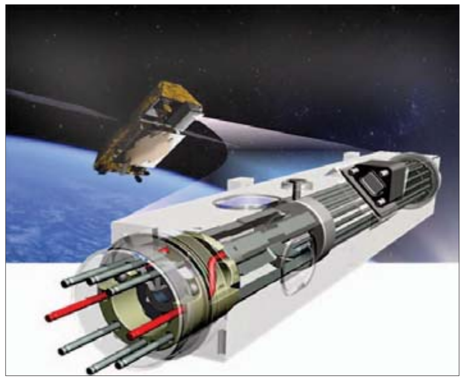
Semiconductors

The discovery of semiconductors brought to the fore the solid state device with the same main property of vacuum tubes — viz, the one-way gate — but with great compactness and economy. Semiconductors are crystals of silicon with trace impurities that release free electrons into the crystal lattice. These electrons help the crystal act as a conductor. A different kind of impurity can also have the same effect by creating a "lack of an electron" or a "hole", which also carries current in the opposite direction. But the interesting thing is that a junction of these two kinds of crystal begins to act as one-way gate — the electrons from one side can pass into the side with the "holes", but there can be no reverse flow of "holes" into the side with electrons. These junctions could then function as single direction connectors.

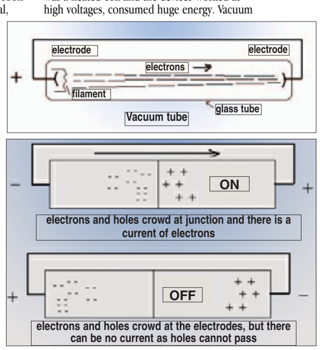
Introducing a third region, where a small voltage had a large affect on the level of current, was again just like the vacuum tube amplifier and these were the transistors.

Vacuum tubes, where the source of electrons was a heated coil and the devices worked at high voltages, consumed huge energy. Vacuum tube devices thus generated heat and took up space. Solid state devices, on the other hand, did not pass electrons through a vacuum. Unlike vacuum tubes, which had to be built with complex internal components, solid state devices were just slivers of crystals that had been grown to serve the purpose. Solid state devices were thus smaller, handy, consumed less power and did not get hot.

Methods were discovered to manufacture panels of many semiconductor devices on the same sheet of crystal and it became routine to compress whole arrangements of devices into a single, postage stamp-sized chip of silicon. The technology has progressed and now single chips can contain thousands or hundreds of thousands of diodes and transistors. The economy of production and operation, along with the compact size, has spawned the huge market of consumer electronics. The plunging costs have enabled complex devices being embedded in everyday devices to automate, for instance, a refrigerator or a washing machine. Such versatility increases the market for the devices and brings the cost further down. The result, apart from inexpensive devices, personal computers, cell phones and even sophisticated, high-level computing, has been the near extinction of the old vacuum tube electronic device. Even in the area of TV screens and display devices, the LED and LCD panels have replaced the vacuum tube.



An artist's rendering of a vacuum tube, one of the main components of an atomic clock that will undergo a technology flight demonstration.



Survival trait

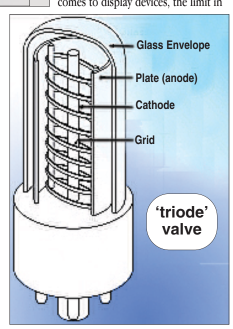
For all their success, solid state devices are not better in all circumstances. The speed of electrons in passing a current through a semiconductor crystal is slow compared to the electrons in a vacuum tube. This is true both of the power current as well as the control signal. Very high frequency applications are thus not possible with solid state devices. Even when it comes to display devices, the limit in solid state is the size of the LED/LCD. In the case of the vacuum tube and electron beam, it is the grain of the chemical coat, which can be many times finer.

Yet another limitation is that solid state devices depend on the electronic state of atoms that compose the crystals. These states are sensitive to strong electromagnetic disturbances and solid state devices need special protection. The vacuum tube device, on the other hand, is less sensitive in its working, to external disturbances. The time of travel of electrons in vacuum tube devices is also less than in semiconductors.

Semiconductors are also not suitable in the presence of varieties of radioactivity, or in some conditions in outer space. In such conditions and for critical applications, thus, vacuum tube devices still have a role to play. One such is if there is a nuclear war and the army keeps vacuum tube-based back-up equipment for this possibility.

In this context, the development to be reported in *Applied Physics Letters* is one that stakes out an important position for the vacuum tube in the future. Scientists at the National Aeronautics and Space Administration's Ames Research Center in Moffett Field, California, and the National Nanofab Center in Korea report a new device – the vacuum channel transistor, constructed using crystal growing methods of semiconductor electronics, and only 150 nanometres long. Although this is more than the 22 and 32 nanometres of solid state transistors in silicon chips, it is a great advance in miniaturisation and ease of manufacture, while maintaining the fast operation of a vacuum device. Apart from size, it has been worked, as of now, at 10 volts, and this could be brought down to one volt.

What we have then is the stability and speed of a vacuum device with comparable size, low power operation and ease of deployment, as a solid state device. It is sure to be found now in many places where solid state devices cannot work or are not fast enough.



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Questions matter

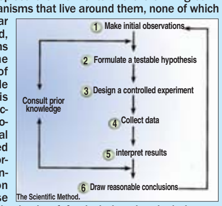
tapan kumar maitra **dwells on biology, 'facts' and the scientific method**

IF asked what they expect to get out of a science textbook, most readers would probably say they intend to learn the facts relevant to a particular scientific area the book is about — cell biology, in the case of the text you are reading right now. If pressed to explain what a fact is, most people would probably say a fact is "something that we know to be true". That sense of the word agrees with the dictionary, since one of the definitions of fact is "a piece of information presented as having objective reality".

To a scientist, however, a fact is a far more tenuous piece of information than such a definition might imply. The "facts" of science are really just attempts to state our current understanding of the natural world around us, based on observations that we make and experiments we do. As such, a given "fact" is only as sound as the observations or experiments on which it is based and can be modified or superseded at any time by a better understanding based on more careful observations or more discriminating experiments. As one scientist so aptly put it, truth to a researcher "is not a citadel of certainty to be defended against error; it is a shady spot where one eats lunch before tramping on". (White, 1968.)

Cell biology is rich with examples of "facts" that were once widely held but have since been superseded as cell biologists have "tramped on" to a better understanding of the phenomena those "facts" attempted to explain. As recently as the early 19th century, for example, it was widely held (regarded as fact) that living matter consisted of substances quite different from those in non-living matter. According to this view, called *vitalism*, the chemical reactions that occurred within living matter did not follow the known laws of chemistry and physics but were, instead, directed by a "vital force". Then came Friedrich Wohler's demonstration (in 1828) that the biological compound *urea* could be synthesised in the laboratory from an inorganic compound, thereby undermining one of the "facts" of vitalism. The other "fact" was refuted by the work of Eduard and Hans Buchner, who showed (in 1897) that non-living extracts from yeast cells could ferment sugar into ethanol. Thus, a view held as "fact" by generations of scientists was eventually discredited and replaced by the new "fact" that the components and reactions of living matter are not a world unto themselves but follow all the laws of chemistry and physics.

For a more contemporary example, consider what we know about the energy needed to support life. Until recently, it was regarded as a fact that the sun was the ultimate source of all energy in the biosphere, such that every organism either uses solar energy directly (green plants, algae and certain bacteria) or is a part of a food chain that is sustained by such photosynthetic organisms. Then came the discovery of deep-sea thermal vents and the thriving communities of organisms that live around them, none of which depends on solar energy. Instead, these organisms depend on the bond energy of hydrogen sulfide (H_2S), which is extracted by bacteria that live around the thermal vents and is used to synthesise organic compounds from carbon dioxide. These bacteria form the basis of food chains that include zooplankton (microscopic animals), worms and other residents of the thermal vent environment.



The Scientific Method.

Thus, the "facts" presented in biology textbooks such as this one are nothing more than our best current attempts to describe and explain the workings of the biological world around us. They are subject to change whenever we become aware of new or better information.

How does new and better information become available? Scientists usually assess new information with a systematic approach called the scientific method. This begins as a researcher makes observations, either in the field or in a research laboratory. Based on these observations and on knowledge gained in prior studies, the scientist formulates a testable hypothesis, a tentative explanation or model consistent with the observations and with prior knowledge that can be tested experimentally. Next, the investigator designs a controlled experiment to test the hypothesis by varying specific conditions while holding everything else as constant as possible. The scientist then collects the data, interprets the results and draws reasonable conclusions, which obviously must be consistent not only with the results of this particular experiment but with prior knowledge as well.

To a practicing scientist, this method is more a way of thinking than a set of procedures to be followed. Most likely, this is the way our ancestors explained and interpreted natural phenomena long before scientists were trained at universities — and long before students read essays about the scientific method!

When illustrated by a diagram, the scientific method looks very neat and orderly. Not all scientific discoveries are made in this way, however. Many important advances in biology have come about more by accident than by plan. Alexander Fleming's discovery of penicillin in 1928 is a classic example. A Scottish physician and bacteriologist, he accidentally left a culture dish of *staphylococcus* bacteria uncovered, such that it was inadvertently exposed to contamination by other micro-organisms. Fleming was about to discard the contaminated culture when he happened to notice some clear patches where the bacteria were not growing.

Reasoning that the bacterial growth may have been inhibited by some contaminant in the air and recognising how important an inhibitor of bacterial growth might be, he kept the culture dish and began attempts to isolate and characterise the substance. The actual identification of penicillin and the demonstration that it was the product of a mold was left to others, but Fleming is credited with the initial discovery.

Regardless of how accidental such discoveries may appear, however, it is almost always true that "chance favours the prepared mind". Behind the apparent "chance" of each such discovery is the "prepared mind" that has been trained to observe carefully and to think astutely. Regardless of the approach, the conclusions from each experiment add to our knowledge of how biological systems work and usually lead to more questions as well, continuing the cycle of scientific inquiry. And that's good news if you aspire to a career in research, because it's your best insurance that there will still be questions to answer when you are ready to begin.

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Night at the museum

steve anderson **reports on priceless treasures ~ after hours**

IN the 2004 film *Night at the Museum*, Ben Stiller's security guard was in for quite a shock when the exhibited T-Rex skeleton sprang to life and began to chase him around the building. If visitors were expecting such life-risking excitement last week when the Natural History Museum in London opened its doors to some special guests after hours, they may have been slightly disappointed, though hopefully not for long as experts strove to bring the museum's collections to life in their own way.

Last Monday evening saw around 150 Mastercard cardholders visit the museum's Darwin Centre as part of the credit card company's Priceless London series of events, when they were given special access to some of its most treasured specimens. The museum's assistant librarian, Lisa Di Tommaso, showcased original botanical sketches by Sydney Parkinson from Lieutenant James Cook's *HMS Endeavour* voyage between 1769 and 1771, while Alan Hart, collections leader in mineralogy, passed around a weighty chunk of gold nugget and displayed a 4.56-billion-year-old meteorite, among other precious rocks.

Watercolours taken from Sydney Parkinson's original botanical sketches drawn during Captain Scott's HMS Endeavour voyage to Austrailia.

The journey of chocolate, from the 1680s discovery of cocoa beans by Sir Hans Sloane (whose name now adorns the tube station just down the road from the museum) through its medicinal use for venereal diseases and finally to a recipe involving milk being bought by the Cadbury family, was told by Dr Sandra Knapp, principal investigator of the department of botany, alongside volumes of Sir Sloane's original samples.

In a museum famous for its animatronic dinosaur displays, the real prehistoric treasure hidden away is not only the lone Tyrannosaurus Rex skeleton kept outside of America, but the first ever of its kind discovered, and paleontologist Dr Paul Barrett gave visitors the chance to run their fingers down the serrated teeth contained in one half of its jaw.

The evening's pièce de résistance, however, lay deep within the Spirit Building (named so because of the high amount of alcohol preserving its 22 million specimens) in the tanking room. After an impressive display of great white shark jaws and an explanation of the intricate sex lives of deep sea angler fish by fish curator James McLaine, invertebrates curator Jon Ablett introduced guests to a very special resident. So special, in fact, that a call to Damien Hirst's oversized tank designers had to be made before she moved in. The *Architeuthis dux* – or Archie, as she's known to her friends – is a 8.62 metre-long giant squid. She arrived at the museum after being caught by some fishermen in the Falkland Islands in 2004, living in her nine-metre tank in the tanking room since.

So, despite a lack of marauding dinosaurs and reanimated Ice Age cavemen, the night at this museum did at times take its visitors' breath away – even if it was just to avoid the smell of a room full of pickled giant fish.

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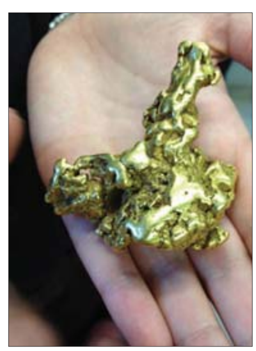

A gold nugget from the mineralogy collection.

One of five of Sir Hans Sloan's original volumes of sketches and specimens collected during his 1680s trip to Jamaica, where he discovered cocoa beans.