their point, I found it useful to paraphrase the question in the following terms: "When we are conscious of what we see, do any of the neural correlates of the images we experience correspond to activity in V1?". Crick and Koch's answer is, none at all. V1 may be active, but the neural correlates for the image of which we are aware cannot be found in V1.

This anti-V1 manifesto is based on two lines of reasoning. The first is the result of reflecting on the connectional patterns of the visual cortices (gleaned from neuroanatomical studies in the monkey), and of considering the possible evolutionary role of awareness. Crick and Koch argue that the best possible use of the images that enter our awareness is in planning behaviour. Because planning depends on frontal cortices, then the contents of visual awareness must be made available to them by the appropriate connections; and because V5 or V4 have such connections, but V1 does not, V5 and V4 are in and V1 is out. The second line of reasoning draws on evidence from both psychophysical and physiological studies. For instance, we cannot turn off the colour constancy effect, something we might be able to do if we were aware of the vagaries of colour processing in V1; nor can we tell which part of a visual image comes from one eye or the other, although V1 is busy processing signals from each eye separately.

As Crick and Koch themselves acknowledge, their hypothesis is both subtle and difficult to test. But it is plausible and it may be a helpful guide, especially if they succeed in specifying precisely which visual areas contain correlates of visual awareness. If we grant that we are unaware of the results of whatever activity is going on in V1, are we then only aware of images based on the activity of 'fifth-tier' areas such as V4 and V5? Or can we be aware of ensemble activity in all early visual cortices minus V1? Might not the ensemble activity of these areas, which are rich in hierarchical and heterarchical projections among themselves, be a better candidate to support images of which we are aware than the outer extrastriate areas alone?

Taken together, the two reports help narrow down the search for the neural correlates of visual experience — that of Tootell and colleagues by demonstrating the involvement of an area in, of all things, a visual illusion, and that of Crick and Koch by proposing the exclusion of a possible area. Neither report claims, as well they should not, that the proposed areas are both necessary and sufficient for visual experience. The finding and the proposal before us specifically concern the neural correlates of the visual images in our minds.

But there is more to experience than that. When the subjects of Tootell *et al.* perceived illusory movement, and knew, automatically and unshakably, that this was their own individual experience, many brain regions outside the visual cortices must have been necessarily coactive to support such subjectivity. A comprehensive mapping of the neural correlates of visual experience, at the level of large-scale systems, must then invoke non-visual brain regions. My own expectation is that the latter includes the entire set of structures, from the brain stem on up to the cortex, which map the body of the organism engaged in seeing and being aware of what is being seen[4]. □

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TECHNOLOGY

Superconducting superwires

Paul M. Grant

"ELECTRICITY is carried by wires. If it weren't for wires, electricity would be useless." I remember vividly it was with these words that my father, an avid Edisonphile and amateur radio experimenter, began my introduction as a young boy to the wonders of electrical science. It is easy to forget the central role this prosaic component plays in all aspects and uses of electricity; arguably, no other technology is so vital to the electric utility industry and its customers. Although copper and aluminium have met most of our wire needs for decades, the demand for conservation and more efficient use of electricity has brought renewed focus on superconductors — materials that have been with us for over 80 years, materials that could yield us veritable 'superwires'.

Despite their marvellous properties, superconductors still do not play much part in our everyday lives. Except for a few niche applications, notably electromagnets for NMR medical imaging, the attendant cost and inconvenience of helium cryogenic refrigeration have simply not justified their widespread use. The discovery in the 1980s of the cuprate perovskites, operable above liquid nitrogen temperature, raised great hopes that the economic balance would now shift in favour of broader application.

At a meeting last month*, progress towards this goal received a well publicized 'leg up' with the announcement of a world-record critical current density at 77 K (S. R. Foltyn, Los Alamos National Laboratory). This result was attained in 'thick' films of $YBa_2Cu_3O_{7-y}$ (Y-123) deposited on flexible metal tapes 5 cm long by 1 cm wide, an embodiment that could in principle be scaled up to kilometre lengths. ('Thick' is here used to differentiate from the 'thin' films of much less than a micrometre typically used in electronic applications.) These tapes, only a few tenths of a millimetre thick, were coated by pulsed laser deposition with Y-123 films of 1–2 μm.

*Spring Meeting of the Materials Research Society, San Francisco, California, USA, 19 April 1995.

The Y-123 films were capable of carrying more than 100 amperes of current with a critical current density in excess of one million A cm^{-2}, well above the requirements, for example, of electrical transmission lines. Of immense importance was that useful levels of critical current density were sustained at nearly 100,000 A cm^{-2} in a 5-tesla magnetic field, thus opening the way for practical magnet wire cooled by liquid nitrogen. The icing on the cake was the retention of this performance when the tapes were coiled to diameters as small as 2 cm. Thus we are approaching the performance achieved in epitaxial films or single crystals, but in a configuration that could be used as a wire. The announcement brings to light an alternative approach to high-transition-temperature (high-T_c) wire that has been under quiet development and improvement in laboratories throughout Japan, the United States and Europe for several years.

This alternative has to be viewed against the background of the present commercially available high-T_c wire. High-temperature superconductors are inherently brittle ceramics, pseudo-orthorhombic in symmetry and polycrystalline, properties not very friendly to wire formation. In a key 1988 paper[1], IBM workers showed that existence of low-angle grain boundaries between neighbouring microcrystals (low angle with respect to the copper–oxygen planes) was essential to obtaining maximal critical current, especially in magnetic field. Prospects for wire appeared dim.

But nature then granted two unexpected favours. The first was that cuprates could exist in thermodynamic equilibrium with metallic silver, permitting its use both as a matrix and as a sheath with which to dress the superconducting ceramic and provide the ductility necessary for wire formation (the wrapping on this first gift was the ease of diffusion of oxygen through silver, allowing post-processing of the cuprate in its final wire form). The second was the discovery of $Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223) with a T_c of

110 K, and double bismuth oxide layers that had the micaceous property of shearing like a deck of playing cards into grain-aligned colonies on crushing and extrusion by the wire drawing and rolling process.

These benefices form the basis for the oxygen (postprocessing)-powder (Pb-stabilized Bi-2223)-in-tube (Ag), or OPIT, wire technology now being commercialized by Sumitomo, American Superconductor and Intermagnetics General. The final product is a silver-clad tape half a millimetre in thickness, about half a centimetre in width, and available in lengths now exceeding one kilometre (ref. 2). Critical current densities in zero magnetic field are length-dependent, ranging from 20,000 to 30,000 A cm^{-2} at 77 K for a few metres, to about 12,000 at the kilometre scale. However, with respect to the proverbial third wish — in this case, robustness in even modest magnetic field — nature was more capricious. The same double bismuth oxide layer so helpful in producing grain alignment serves to degrade critical current to uselessly low values in magnetic fields of only a few tenths of a tesla at 77 K.

Y-123 has long been the material of choice for liquid nitrogen operation because it does retain high critical currents under substantial magnetic fields in epitaxial film or single crystal form. This property is a direct consequence of the stronger vertical coupling between copper oxygen planes provided by the CuO chains in its crystal structure as opposed to (Pb,Bi)-2223. On the other hand, this same feature inhibits the self-grain alignment yielded serendipitously by (Pb,Bi)-2223 and has defeated all attempts to use the OPIT process to make wire out of it. The processability difference between the two materials is readily discernible when grinding them in a mortar and pestle: (Pb,Bi)-2223 gives a greasy, graphitic feel, whereas Y-123 is akin to sand. The goal has been to find a process whereby long lengths of a suitable flexible substrate can be coated with grain-aligned Y-123.

Early on, efforts were made to deposit thick films of Y-123 on nickel alloy tapes of special composition (Hastelloy) chosen to match the thermal expansion coefficient of Y-123. An immediate problem was the diffusion of nickel into the Y-123 film at high processing temperatures, solved by interposing a thin 'buffer layer' of a suitable oxide, most often yttria-stabilized cubic zirconia (YSZ), between the tape substrate and superconductor. Around 1991, a 1-m conductor (in utility industry parlance, a conductor is made out of wires, a cable is what houses the conductor) containing 100 tapes of this design was constructed by Sumitomo Electric, demonstrating that it could in principle be manufactured on large scales. But because the Y-123 layer was polycrystalline with a large distribution of wide-angle grain boundaries, the critical current performance both in and out of magnetic field was disappointing (K. Fujino, results presented at ISS 6 conference, Hiroshima, 1993).

In 1992, workers[3] from Fujikura Ltd obtained a dramatic improvement in properties using ion-beam-assisted deposition (IBAD), a process pioneered by IBM[4] before the advent of high-T_c, to texture the YSZ buffer layer during its deposition. The process can be thought of as preferential atomic sandblasting whereby those crystallographic directions not presenting clear 'channels' to the impinging ion beam (usually argon) are eroded away. The resulting oriented buffer layer then seeds the growth of a deposited Y-123 film in a quasi-epitaxial manner. On centimetre-square samples, the Fujikura group achieved a zero-field critical current at 77 K of 2.5×10^5 A cm^{-2} and astonishing values only an order of magnitude lower at 5 T applied field, outperforming OPIT even at this early date.

Will the combination of IBAD and thick films render OPIT obsolete? There is no question that (Pb,Bi)-2223 will not be able to match its performance at 77 K. Nonetheless, a number of technical problems remain, not the least of which is the feasibility of scaling up a complex thin-film deposition process to industrial volumes and areas while retaining laboratory-level performance. The outlook is hopeful — there are many similarities to methods used today for the mass production of magnetic recording disks for the personal computer industry. Indeed, a preliminary study[5] of manufacturing costs indicates no obvious technical stumbling blocks and suggests that if sufficient demand for high-performance superconducting wire at 77 K were engendered, the Y-123 tape could be produced and sold at a price competitive with current low-T_c wire products used in MRI machines.

So the future of IBAD/thick-film superconducting tape really involves an economic, rather than technical, risk, and we will have to wait and see which entrepreneurs or companies surface with the courage (or foolhardiness!) to take it on in expectation of the reward returned by a potentially large market. But isn't this what Adam Smith told us capitalism was supposed to be all about? □

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DAEDALUS

Twisted currents

ELECTRONS have spin. They can spin in either of two directions, and the two need not be equivalent. The electrons emitted by radioactive β-decay spin preferentially to the left, for example. Daedalus has uses for a beam of left-spinning electrons. In an electron microscope, it should be preferentially scattered by left-handed molecules; a neat way to spot chiral regions in a biological specimen. In a television cathode ray tube, it should emit left-circularly polarized light. But a β-emitter is not ideal as an electron gun for instrumentation or imaging purposes. So Daedalus proposes another source of polarized electrons.

It is based on the spin-flip laser. In a magnetic field, the conduction electrons in indium antimonide can spin either with the field or against it. The ones spinning against the field can shed their higher energy by executing a 'spin flip' which emits polarized infrared radiation and leaves them spinning with the field, like the others. Soon all the conduction electrons will be spinning the same way. Pass a current through the semiconductor, and you could flush them out. Spin being conserved, they would retain their spin throughout the rest of the circuit. The result: circularly polarized electricity.

The first large-scale applications of polarized electricity will be polarized LEDs and electroluminous panels, the first efficient sources of polarized light. Many previously unfeasible optical schemes will become practical: glare-free screens and control panels, car headlamps which illuminate but can't dazzle, stereo television and so on.

But Daedalus has further uses up his sleeve. Chiral electricity should carry out chiral electrochemistry. At the moment this can be done after a fashion at electrodes with molecularly chiral surfaces; but polarized electricity should do it perfectly. Specific optical isomers will be accessible directly in 100 per cent yield. The pharmaceutical industry, always seeking to match its products to the chemistry of life, will be delighted. And with luck, a chiral storage battery will also work. It will accumulate polarized electricity, and release it on demand. The user will be able to buy the new product in battery form, rather than having to maintain a tricky spin-flip generator. The only snag is that polarized electricity will take time to get going. A voltage is established at the speed of light; but the electrons of the circuit amble along at a much slower pace. It may take hours to flush out a new circuit with polarized electrons, and reap their lopsided benefits.

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