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.

David Jones