Accelerating HTSC Electronics*

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It's almost three years now since high temperature superconductors burst into—and in some cases changed—our lives. Since then, R&D has solidified, refining earlier discoveries, extending them slowly into other realms and other chemistries, and cautiously exploring possible applications. The initial rush of public excitement has subsided, and most of the world has settled into a wait-and-see attitude about the importance of high temperature superconductivity.

Unfortunately, I'm afraid that the wait-and-see attitude has also cropped up in some places where it shouldn't have—in places that affect the direction and intensity of the R&D process. I'd like to explore that situation here, and in doing so I'd like to pose, and try to answer, four questions.

The four questions are these. First, did we respond appropriately to the initial opportunity? Second, are we conducting the right mix of R&D now? Third, how effective and appropriate is government's role in superconductivity R&D? And fourth, has the response from business been appropriate to the opportunity?

My own reaction to the initial announcement was one of tremendous excitement—but not for the same reasons as a lot of other people. Obviously, to some extent it was the sheer delight at seeing a long-time barrier shattered—having spent many years myself working in low-temperature research.

But despite my own longstanding involvement, my thoughts turned quickly to possible implications in another area—electronics. Given the materials problems of the new superconductors, and what the current density limitations are, it seemed that thin-film applications might be the easiest to realize. And IBM and others had done a great deal of recent work on Josephson junction effects in cold superconductors, so we already had a base to build on.

But, virtually all the vocal attention centered initially on applications requiring bulk superconductors—notably wires and magnets. In the articles being written about what superconductivity might do for us, electronics was usually a paragraph near the end, and even that was taken up mostly with applications to SQUIDs for limited military uses. There were a couple of reasons for that persistent slant. Those *were* the dominant existing applications for superconductivity in most people's minds. People could easily see the leaps in performance if superconductivity could be applied to mechanical or power systems—what emerged in the public eye as flying trains, super-efficient motors, and even tabletop particle accelerators. The other reason for that skewed interest is human nature: People are quick to picture something as a replacement or an extension of something that already exists.

We might call that the "vacuum tube phenomenon." When the transistor was first announced, it was seen, and initially pursued, as a replacement for the vacuum tube. And it was. Yet anyone who tried to assess the market potential of the transistor on that basis missed the mark by orders of magnitude. Transistors were important not because they replaced tubes but because they re-invented electronics. Once we understood that semiconductors permitted revolutionary concepts of electronic design and function, a new industry—in fact dozens of new industries—took off.

I've been thinking about warm superconductors in a similar, qualitative way. But I've found that many people continue to think of them largely as one-for-one replacements. So we hear arguments along the lines of: "Plugging a superconducting microprocessor into a computer circuit design isn't likely to be worth it because we'd be still limited in throughput in the rest of the system." That may be an appropriate answer, but it's not the right question. I'd rather look at how the availability of a microprocessor using superconducting effects might offer enough advantage to justify a circuit design without the throughput limitations. Is that feasible? I don't know. But I do know that assessing new phenomena in that kind of design isolation prejudices the range of solutions and precludes finding the potential advantage.

At any rate, my response to the announcement by Bednorz and Müller was one of real elation. It looked to me like a potential shot in the arm to our microelectronics industries—and by that I mean chips, computers, sensors, and so forth. The reason was straightforward. No country, and no companies, were as far along in exploring superconducting phenomena and applications as we were in the United States. Warm superconductors were the technological ground floor for everyone and offered a chance for U.S. industry to compete strongly in a new technology.

It also gave us a chance to see how various institutions that had been absorbing harsh lessons from the world marketplace over the past decade would respond to fresh opportunity. In hopes of speeding that process, a group of us in Washington, DC conceived of what became the Council on Superconductivity for American Competitiveness, a trade organization dedicated to helping government and industry mount that very response.

We discovered something perhaps not unexpected. Our institutions responded best to warm superconductors in terms of scientific phenomena. That is, relatively quickly government was able to funnel more money into established lines of research. As everyone knows, there's always lots of money in Washington to study problems and phenomena. So it was easy to activate the basic research sector to extend its efforts into the realm of warm superconductors; indeed, the rush to warm threatened to ignore some potentially important new wrinkles in cold. But the rush was taking place in a limited realm, with little real attention devoted to the technology potential. It was almost as if we were determined to exhaust the search for room temperature superconductors before we settled on a working material.

But there's an important point to remember with regard to warm superconductors—and with regard to the immense dedication to the race to find warmer and warmer superconductors. That race may not be the most promising way to take advantage of the phenomenon itself. Our appetites for warmer and warmer superconductors shouldn't blind us to a couple of looming physical constraints: (1) there's the Curie temperature, the limit to how warm a material may be and still retain magnetic ordering (the highest of these Curie temperatures are at about 600 K); (2) in many applications, including

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electronic devices, superconductors are likely to be limited to operating at no more than 50-75% of their critical temperature; and (3) superconducting devices operating at room temperature would therefore have to have critical temperatures of at least 400 K, and perhaps closer to 600 K. That possible convergence of critical temperature and Curie temperature is not encouraging, because it suggests that we would require a rare and fortuitous free gift from nature to be successful.

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On the other hand, we might be able to achieve room temperature operation—which is what really counts—of devices with superconductors even if we can't achieve transition temperatures any higher than we already have today. We might do that through novel refrigeration techniques, perhaps very localized or very integral with the electronics. The issue is not whether you can maintain non-ambient conditions within a device; we do that all the time, from light bulbs to car engines. The issue is if you can achieve operating benefits big enough to offset the costs of maintaining that non-ambient environment. It's a question that I think deserves very serious consideration, because a positive answer would be a powerful boost to near-term technology developments.

I think we can make a strong case that, for purposes of device design, the breakthrough we had early-on—up to liquid nitrogen temperatures—was sufficient to demand attention to how we might use it. but our institutions responded much more slowly in the area of new applications and in the areas of processing and manufacturing, with one notable exception. One corner of government deserves a lot of credit—DARPA. A couple of people in DARPA saw, quickly, that the prospects for early technology leadership hinged on how quickly we could apply some of our research efforts in warm superconductors to devices and manufacturing. Kay Rhyne Adams (now at Lockheed) came charging out of DARPA early in 1987 with a program to do just that. Her approach was straightforward: Get people to start thinking about applications and to start trying to find out how to harness those brittle, unstable materials.

Her two years of persistence paid off. DARPA's program, even though it should be larger, is the best the U.S. government has put together, and for a couple of reasons. First, it emphasizes devices, or products—a seemingly basic element that's often a missing ingredient in U.S. technology programs. Second, the emphasis on devices and manufacturing will counter the tendency of this field of research to languish in the basic research end of the R&D spectrum. Third, it takes seriously its responsibility to speed the development of *products* for its customer, specifically DOD, but more generally, all of us. Fourth, it's using this opening of a new field to encourage innovative research partnerships. If, as George Gilder insists, the strongest and most important element of American technology is found in small, innovative companies, then DARPA's programs are trying to find ways to leverage that strength in the pursuit of national technology leadership.

But, in general, I stand by this observation: The federal government made some noise and moved some dollars around, but the few innovative new programs to gain experience in manufacturing and device development have been treated like stepchildren. And in my experience, American industry, with some laudable exceptions, has not been much more encouraging so far. Programs have developed slowly, and remain relatively small, even today. To be sure, we see some companies where superconductivity is looked on as a real opportunity, but in most it is something to be watched, or pursued modestly, but definitely not chased. I'm afraid that attitude will result in our discovery, a few years down the road, that not only are the interesting things to watch taking place in Japan, but by the time we get interested enough it is going to be awfully late to chase them.

So the answer to my first question, did we respond appropriately to the initial opportunity, is simply no. What that tells us reflects less on superconductivity and more on our attitude toward technology. I think it's rooted in a persistent U.S. underappreciation of—or amnesia about—the importance of superior products as the essential determinant of business success. Again, there are happy exceptions, but those exceptions should be the rule. If they were, we'd make technology development and its incorporation into industrial output a top priority in both business and government.

We don't have to look too hard to see a counter example, one we're bound to learn from one of these days. Whatever else drives Japanese industrial success, it's driven by an unrelenting focus on developing new products for customers. But in the United States, making products is merely *one* of the ways our companies arrive at their bottom line—and not necessarily the most valued. What counts in the long-run is adding value to society. When all is said and done, when companies have been sold and subdivided, rationalized and depreciated, merged and off-shored, it is the goods and services that are produced that support the economic system—and that will be the ultimate measure of a company's success.

Now, that kind of simple analysis almost always gets nods of recognition—quickly followed either by excuses for why product development has to fight so hard for priority in companies, or more typically, by complaints about how the financial and regulatory worlds conspire to discourage long-term investment in new technology. One of these days, when the financial people have run out of ledger tricks to turn a profit, they'll come back to products. I hope it's soon, and I'm doing my share of agitating to speed the process. In the meantime, we better be ready to respond.

In a way I've already answered my second question: Are we conducting the right mix of R&D now? I don't think so. I'd put more funding into programs like DARPA's, because they have such good prospects for generating innovative ideas for new applications. And I have urged, and continue to urge, business to be more aggressive in its programs, especially those businesses with substantial R&D resources.

One particular project that I've been associated with will, I hope, turn out to address both those concerns. In one of DARPA's recent research contracts, the Council on Superconductivity for American Competitiveness rounded up some half dozen of the more eager companies doing research on superconductivity applications in a collaborative effort. The project is pragmatically described by its title: "Paths to Manufacturable Superconducting Microelectronic Devices." The participants in the project are eager to make things. Over the next year, under the technical direction of Bruce Murdock of Tektronix, the group will be surveying, sifting, and evaluating potential applications of superconductivity to microelectronics. Bruce and his co-researchers are casting a wide net, and a year from now they hope to have in hand a few high-potential applications worth further focused work. Maybe that superconducting microprocessor will be among them, maybe not. The fact is that we don't know enough yet to

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assess its potential, but we expect to learn fast.

This project, I hasten to add, is a wide-open process. Results will be made available to the entire research community and, conversely, the entire research community should feel free to interact with the project as it moves along. Anyone who is interested is invited to contact Bruce Murdock at Tektronix. We expect the project to continue in some form after this first year, because it will no doubt require some follow-on to further test the feasibility of the concepts—through simulations. But it's also likely that, at the same time, the companies themselves will be ready to follow up with some device development.

We have also been working to set up a formal consortium of many of those same companies to pursue those private sector efforts. We are calling the consortium SuperChip, and I expect it to take firm shape during the coming year. Again, the primary purpose is to take advantage of the synergy of a number of diverse—and relatively modest—industrial R&D programs working together.

But there's a secondary purpose for SuperChip as well—to explore effective ways for U.S. companies to collaborate in R&D. That collaboration is a strength of the Japanese companies, and it's a weakness of ours. Attempts over the past half dozen years to forge R&D alliances have hardly met with resounding success, although U.S. companies are getting smarter about how to advance mutual interests. If for no other reason, we don't usually make the same mistake twice. Our own concept for SuperChip mimics the strengths of a vertically integrated company by selecting complementary, rather than competing, industrial members. If the chief weakness of earlier consortia has been a reluctance of members to share technology, this may be a way—in fact, it may be *the* way—to reduce the disincentives. To learn more about SuperChip, contact Kevin Ott, Executive Director of the Council on Superconductivity for American Competitiveness.

The third question I posed earlier related to the effectiveness of government's role in superconductivity R&D. I wish I could be more enthusiastic, and I hope I *can* be in the near future. I already offered what I think is government's most innovative contribution—the kind of applications-oriented, industrially linked program DARPA mounted. But I also referred to it as a stepchild, and were it not for some impassioned and effective advocacy from within DARPA and by some of its strong supporters, that program might have been squeezed out—a mouse trampled by fighting elephants.

What has been generally missing in government's response is a sense of urgency or a sense of grabbing an opportunity. In large measure this stems from a structural weakness in government when it comes to technology—how to stimulate it, what government's role ought to be, and how to consider its importance at policy levels. It's not surprising that one of the few places that seems comfortable with technology is the Defense Department, because DOD is obligated to generate technological solutions to meet its needs.

But, as people are coming to recognize these days, technological leadership is a requisite for international leadership in more than defense. Government is poorly prepared to exercise that role and will remain so until there's a reordering of government priorities and a shuffling of responsibilities. I continue to hope that things like superconductivity, or high-definition television, or microchips, or similar issues that clearly impact the industrial and the government sectors, will help us to highlight and clarify the problems—and respond to them. So far, it's still uphill, but it's going to crest one of these days, and I think soon.

Finally, my fourth question: Has the response from business been appropriate to the opportunity? I lean to saying no, but I'm more inclined to put that in the larger context of inadequate attention being paid to technological advantage in general, and failure to focus heavily on incorporating new technology into products as a source of advantage in the marketplace. It may disappoint me that a large company makes only a token effort in superconductivity, but it disappoints me far more that the large company has similar attitudes toward many new technologies. I've argued with a lot of business colleagues over the past few years about this issue, and I'm sympathetic—but only up to a point—with their insistence that market forces make it hard to justify investment in the kinds of long-term R&D that lead to new products.

I've stressed the importance of superconductivity to microelectronics for two reasons. First, I've already explained: I think it's not only the easier technical problem to solve because of materials problems, but my gut feeling is that there could be some unexpected and immense payoffs in performance from whole new design concepts. The other reason is also sound business, and that's the irrefutable evidence of the growing importance of information technology in international economics. This is becoming an immense industry, and the technology that underlies it, and that speeds it along, will acquire enormous economic value. I recently heard some Japanese technology planners at both MITI and NEC estimate that within 25 years, something on the order of 30% of the Japanese GNP will be connected to information transmission and use and the products needed to accomplish that. We ourselves are seeing how telecommunications and computers are growing towards each other, and towards some kind of hybrid technology that sweeps up television as well. And it's hard to find an area of business today that is not influenced, or even dominated, by information technology. And that is a trend that shows no signs of slowing.

I said earlier that we do not yet know what impact superconductivity might have on microelectronics, which is as good a surrogate for information technology as anything. But I do know that when something comes along that holds out a possibility of changing the equation for something as important to an economy as information technology, we better not be caught flat-footed. Many of us have been to Japan. We've seen the effort and care devoted there to technology and product development, and we know that is a major element in the success of Japanese companies. And we've seen aspects of the thoughtful, comprehensive approach they've taken to superconductivity R&D as well. I mentioned earlier that we have a chance to put into practice some of the hard-learned lessons in technology competition gained over the past two decades. And the lesson I've come away with is the one emphasized here—the importance of products and technology as industrial differentiators. The opportunity to apply that lesson to superconductivity remains open, and possibly immense.

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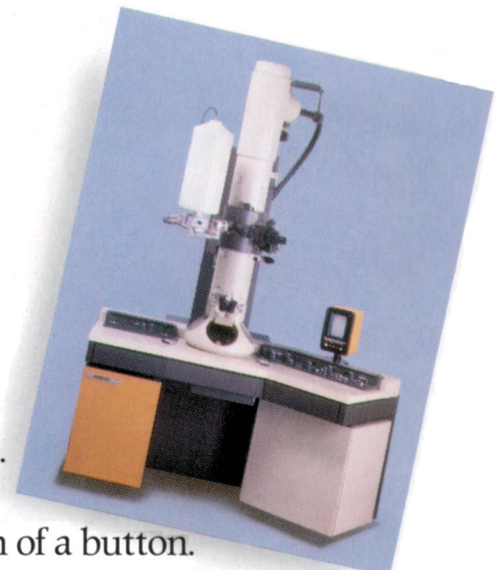

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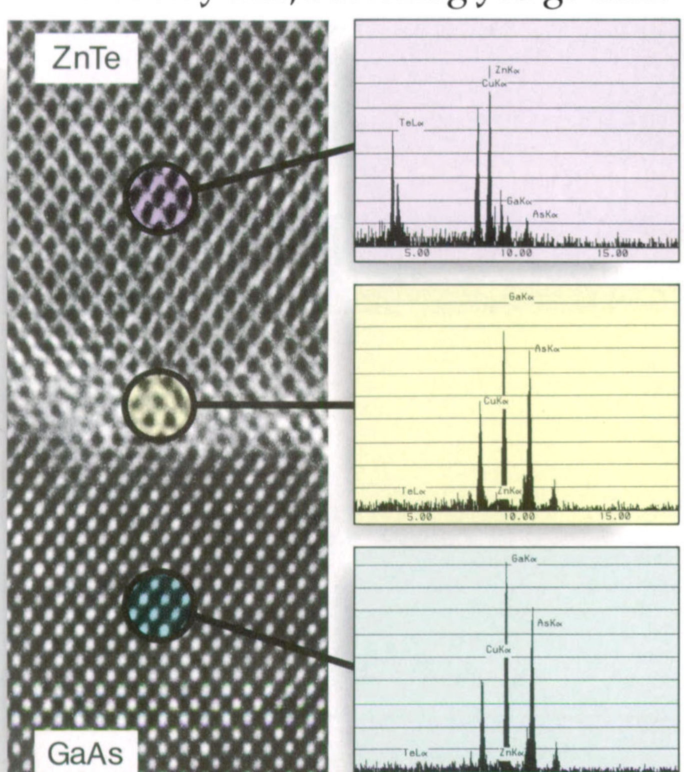

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