US SUPERCONDUCTIVITY EFFORT SHAPES UP, WITH DU PONT EMERGING A BIG PLAYER

E. I. du Pont de Nemours & Company, Hewlett–Packard and Los Alamos National Laboratory have announced their intention of forming a consortium to develop thin-film, high-temperature superconductors for electronic components. The collaboration is to involve the equivalent of 25 or more researchers and equipment estimated at about $10 million. There is no commitment of funds as yet, but a formal agreement is to be reached by the beginning of October.

The new consortium was announced about a month after AT&T, IBM and MIT's Lincoln Lab established a similar group to work on superconducting electronics (see PHYSICS TODAY, July, page 61), and about a year after Du Pont joined Microelectronics & Computer Technology Corporation in a collaboration with C. W. (Paul) Chu's team at Houston. The formation of the three consortia signals a firming consensus that high-temperature superconductivity will have important applications in electronics in the medium or long term. The news also marks the emergence of Du Pont as a major player in superconductivity.

Du Pont is one of the few companies that have entered into cooperative research agreements with all three of the Department of Energy's designated High-Temperature Superconductivity Pilot Centers at Oak Ridge, Argonne and Los Alamos. These centers were established at the initiative of John Herrington, Secretary of Energy in the Reagan Administration, to enter into research arrangements with industry. Each center receives about $1.6 million a year in funding—just part of each lab's total funding for superconductivity.

In addition to participating in the Houston–MCC consortium, Du Pont has bought rights to all patents earned by the materials group headed by Paul Chu at the Texas Center for Superconductivity in Houston. The center appears at this writing to be the most elaborate and well endowed of the academic superconductivity centers, with an annual budget of $10 million. It has 30 faculty members, 30 postdoctoral fellows and 50 graduate and undergraduate students and staff. Texas is putting up a $22.5 million building for the center, in which each lab is being custom-designed by its principal investigator.

Two-tiered industrial system

What seems to be crystallizing, on a substrate of opinion that major applications in electronics will require years or decades of sustained and well-organized research, is a two-tier industrial system in superconductivity. The giants such as Du Pont, IBM and AT&T are joining with one another, academic partners and national labs for the long haul. Much smaller startup companies are focusing on more near-term development of materials, especially thin films, and specialized applications like instruments and devices. Some of the larger electronics companies such as Hewlett–Packard are adopting an intermediate position, entering into arrangements both with the giants and with the upstarts.

One of the interesting new companies, Hypres Inc, predates the discovery of the high-temperature superconductors. Located in Elmsford, New York, Hypres was founded six years ago by Sadeg Faris, who until recently was its chairman. Hypres continues to work primarily on applications involving low-temperature superconductors. Its first product was a high-speed oscilloscope relying on liquid helium cryogenics. It is developing a Josephson junction chip that operates at 4 K on one side but has regular semiconductor components on the other, which operates at room temperature.

Hypres also is developing niobium and niobium nitride superconducting devices, which can be operated at twice the temperature of liquid helium, permitting the use of commercially available refrigeration technology. It has developed and is marketing a chip based on the technology.

DARPA has made a $2.6 million award to Hypres to develop novel devices employing high-temperature superconductors. Faris, a former senior scientist at IBM, where he worked on the Josephson computer project, has expressed confidence at public presentations that there will be important high-temperature superconductor applications in Josephson devices, transmission lines between chips and integration of multiple functions on single wafers. He has said that a subnanosecond-clock-rate 4-bit processor developed by Fujitsu demonstrates the basic elements of superconducting technology.

Conductus, STI

Faris's optimism is shared at Conductus Inc, which was founded in September 1987 to develop superconducting technology for applications such as very-high-speed digital devices, magnetic field detectors and high-speed interconnects for integrated circuits. Originally based in Palo Alto, Conductus has relocated to Sunnyvale, California. Its board consists of representatives from several Palo Alto companies, notably Regis McKenna, a business consultant known for electronics marketing, and Frank Carrubba, director of Hewlett–Packard Laboratories. John Rowell, who collaborated with Philip W. Anderson on the first experimental observation of the Josephson effect, is research director of the company. Its scientific advisory board consists of the Stanford and Berkeley researchers Malcolm R. Beasley, John Clarke, Theodore H. Geballe, Robert H. Hammond, Aharon Kapitulnik, Paul L. Richards and Theodore Van Duzer.

Last year Hewlett–Packard joined in a cooperative research agreement with Conductus that specifies activities and a division of labor. The total value of the agreement is thought to be comparable to the original capitalization of the firm. Conductus also

has an exclusive arrangement with Lawrence Berkeley Laboratory to market products based on the lab's SQUID patents. An agreement with Bellcore is considered imminent at this writing.

Peter Cannon, the president of Conductus, sees the niche for the company, and for high-temperature superconductors in general, as being thin film electronics, "where the critical current and magnetic flux creep issues don't just kill you up front." He sees prospective performance advantages in terms of switching speed, and he thinks those advantages "go a lot further than just making something like silicon that runs faster, in that you also have a great sensitivity to magnetic field, which should be usable in the context of entirely new inventions of devices. . . ."

Conductus currently has a professional staff of about 15 and is capitalized at $11.5 million. Cannon says that its stockholders expect to see commercial products emerge from the company within five years of its establishment, meaning by 1992 or so, but he says he expects to see the company sell something "sooner than anybody would have expected a year ago."

A second California company, which some consider to be better established and "far ahead" of Conductus, is Superconducting Technologies Inc. Based in Santa Barbara, STI was founded in May 1987 by venture capitalists and researchers, notably Robert Schrieffer.

STI is concentrating on development of thallium compounds, thin film and microwave applications of thin films.

National Planning for Superconductivity Competition

Partly because of efforts by groups like the Council on Superconductivity for American Competitiveness, and partly because of consensus reports by groups and organizations such as Ralph Gomory's panel of "wise men" and the Office of Technology Assessment, superconductivity has come to be defined as a test of US ability and will to rise to the Japanese challenge. Reciprocally, the Japanese are said to regard superconductivity as a test of their ability to build a technology from the ground up, rather than adapt basic research done elsewhere and win out only in the engineering phase.

At every US conference and in every major report on the subject, Americans are reminded of Japan's International Superconductivity Technology Center, a large consortium established last year to do R&D. Each of ISTEC's 50-odd members has paid an initiation fee of about $1 million, and each has committed two full-time researchers under the age of 35 to the center. In addition, another 100 or so companies are associate members, including Japanese subsidiaries of some US companies such as Du Pont, the Electric Power Research Institute, IBM and Rockwell.

Separately from ISTEC, Japan's Agency for Industrial Science & Technology has made a commitment of $800 million to six Japanese companies for a 10-year project on superconducting electronics. By comparison, the efforts mounted by the three US consortia and the small startup firms look somewhat paltry.

In a report last year on "commercializing high-temperature superconductivity," OTA raised questions about whether a more concerted national effort is warranted in the United States. "With the knowledge base ever larger and more specialized, the great majority of American firms, large and small, can no longer expect to be self-sufficient in technology. . . . Industry depends more heavily than ever before on the huge Federal R&D budget. . . . Nonetheless, the US government has left most questions of R&D funding to the mission agencies, with their focused interests and immediate needs. While other countries have crafted policies for direct support of commercial technologies, the United States has not."

In particular, OTA wondered whether the Department of Defense and DOE were not accounting for an excessive share of US government expenditures on superconductivity, and it complained that most government expenditures represented reprogrammed funds. The OTA report suggested that Congress should evaluate trade-offs at the agency level, consider additional appropriations and encourage more interagency coordination.

At a recent CSAC conference in Washington, concern was expressed about whether the government is moving quickly enough on a large number of fronts to respond adequately to the Japanese challenge. Specifically:

▷ The National Commission on Superconductivity, which was established last year in the Omnibus Trade and Competitiveness Act, with the mission of reporting to the President and to Congress on ten questions, awaits a charter from the White House so that it can start work. Without the charter it cannot spend money, reports David McCall of AT&T Bell Labs, its chairman.

▷ A national action plan for superconductivity from the President's Office of Science and Technology Policy, called for in the McCurdy–Ritter National Superconductivity and Competitiveness Act, seems to be nearly completed but has yet to appear. Clean air legislation and the future of NASA are thought to have been higher OSTP priorities. (The McCurdy–Ritter act also authorizes a Department of Energy technology transfer program in superconductivity, which is just starting to be organized.)

▷ The National Institute for Standards and Technology has no director and no technology chief.

▷ Creation of a competition office in the Commerce Department is under consideration but does not appear to be going anywhere fast.

▷ The same is true, *a fortiori*, of a suggestion by Senator John Glenn, among others, to create a civilian counterpart to DARPA.

DARPA still is behind a great deal of the US activity in superconductivity and has agreed to fund, for example, a $600 000 CSAC study to determine the most promising applications of superconductivity in electronics. Questions may be raised about he propriety of DARPA's funding an organization that is in the business of persuading the country to give government agencies like DARPA more money. CSAC staff respond that it is not the organization's main purpose to provide a "gravy train" for industry.

CSAC's most ambitious current project is a plan it is hatching for creation of a corporation called SuperChip, and the council is looking for a large loan guarantee from the Federal government to get started. Legislation providing patent protection and antitrust waivers also would be required, says Kevin Ott, the executive director of CSAC. What CSAC seems to be looking for is creation of an organization comparable to Japan's ISTEC —WS

It has a staff of about 25 professionals, and most of its work currently is for the Federal government. One of several dozen organizations receiving support from DARPA in superconductivity, it has a $7 million, three-year contract with the agency. It has a joint research agreement with UCLA, Northrop, TRW and Hughes.

American Superconductor

Another of the fast-moving smaller companies, also benefiting from academic spinoffs, is American Superconductor Corporation. It was founded by a group of MIT materials science and engineering faculty primarily to develop and produce superconducting microcable. The company's approach, an alternative to the standard ceramic processing techniques, involves producing and forming the metallic constituents of the superconducting oxides prior to oxidation.

The focus of the company is on the development and manufacturing of wires, foils and films for conductor applications, which it believes will be commercialized well ahead of high-temperature Josephson junctions for active devices. "The need for extremely high-quality surfaces of thin films for active devices, and problems associated with reactions between thin films and their substrates, will delay the commercialization of active devices," according to Gregory J. Yurek, president of American Superconductor. "The problems here rival those of the field dependence of critical current and flux pinning in conductor applications."

Like Du Pont, American Superconductor has entered into cooperative agreements with all three of the national laboratories in the DOE pilot program. The most recent is with Los Alamos and concerns optimization of thin films for applications in infrared sensors and for low-loss, microwave and millimeter-wave circuit applications.

Speaking at a conference held in Washington, DC, on 23 June, the day after the agreement with Los Alamos was announced, Yurek said the DOE pilot program was very valuable to companies like American Superconductor. Yurek indicated, however, that there had been problems in negotiating model agreements with the labs, and he noted that agreements tended to get snagged in the DOE bureaucracy after being drafted. One major issue concerned disclosure of information gained in the context of individual cooperative arrangements. Evidently DOE wanted to make all information available to all participants in cooperative agreements, but that was unacceptable to American Superconductor and some other companies. "That would be a consortium, not a pilot center," said Yurek.

Optimistic mood

The conference where Yurek spoke was held under the sponsorship of the Council on Superconductivity for American Competitiveness—an organization representing companies in the superconductivity business. Ironically, the conference took place shortly after a number of publications with general readerships had published articles about flux creep and raised the question of whether the superconductivity "party" was over. (For an account of flux creep, see PHYSICS TODAY, March, page 17). A lot of the conference participants were irritated by the inference that flux creep doomed the outlook for industrial applications of superconductivity, and several said so from the podium.

Praveen Chaudhari of IBM, reporting on the Gomory panel's findings, said that contrary to recent news reports there are "no inherent problems with the new materials" in the single-crystal form. What matters, he said, was getting the critical current and field and the material properties that you need for the particular application in mind. Edward J. Mead, business manager for superconductivity at Du Pont, said that what currently is being done in superconductivity in the United States is embarrassingly little compared to what could be done. Wei-Kan Chu, reporting on a superconducting transistor the Houston group claims to have invented, said enthusiastically, "The party's just beginning."

With reports on the three national lab pilot programs, and talks by Chaudhari, Mead, Yurek and David W. McCall of AT&T Bell Labs, the chairman of the National Commission on Superconductivity, the conference provided ample evidence of energetic activity. Even Kenneth Klein, the director of DOE's Office of Energy Storage and Distribution, managed to convey a sense of high drama in a talk on long-term prospects for using high temperature superconductivity in large-scale applications. Generally, he said, a critical current of 10^5 amperes/cm^2 is what is required to get into interesting applications.

Had the conference paid more heed to the academic world, rather than staying rather strictly focused on industry and government, there would have been even more evidence of activity. Small academic centers inviting industrial participation are being set up all over the place, and an NSF Center for Superconductivity has been established in Illinois as a joint effort of the University of Illinois at Urbana–Champaign, Northwestern University, the University of Chicago, and Argonne National Laboratory. NSF also is supporting, together with the Air Force Office of Scientific Research and a number of other companies, a superconductivity center at Stanford University. The University of Minnesota and the State University of New York at Buffalo are setting up superconductivity centers using a combination of resources including state money and windfalls from the Federal stripper-well fund.

Arthur Sleight, recognized as a pioneer in oxide superconductors (PHYSICS TODAY, April 1987, page 17), is leaving Du Pont to establish a team at Oregon State University in Corvallis. Allen Hermann, the discoverer with Zhengzhi Sheng of the thallium-based superconductors, is leaving the University of Arkansas to build a team at the University of Colorado in Boulder. The National Institute for Standards and Technology (formerly the National Bureau of Standards) also is building a superconductivity group in Boulder. Maw-Kuen Wu, who discovered the liquid-nitrogen-temperature superconductors with Paul Chu, has left the University of Alabama for a professorship at Columbia University.

The one nod the conference made to the academic world was a report by Wei-Kan Chu, which was scheduled for the end of the afternoon, on the Houston center's newly announced transistor. Almost the entire audience stayed in a packed room till the end, listening intently if also somewhat skeptically to the presentation on the transistor.

Houston transistor

Described as a high-temperature superconducting magnetic-field-effect transistor, the device consists of a micron-sized electromagnet that produces very small magnetic fields perpendicular to a superconducting layer. Varying the size of the magnetic field controls the amount of resistance in the superconducting material.

Wei-Kan Chu says that a report on the transistor was submitted to *Applied Physics Letters*, and that it has been returned with a rather critical comment from a referee, which he feels misses the point. He says that he and his coinventors, Zu-Hua Zhang and Yuan-Yun Zhao, are modifying

the article and preparing a "rebuttal" for the referee. Consequently Chu is not ready to distribute the manuscript or the illustrations he presented as viewgraphs in Washington.

Chu says the concept is unique to the new superconductors because it makes use of resistance induced by small magnetic fields as a switch. "That way we are using a curse to our own advantage."

—WILLIAM SWEET

MICHIGAN TEAM TO JOIN IN FIRST EXPERIMENT AT SOVIET ACCELERATOR

A US team led by Alan D. Krisch of the University of Michigan will cooperate with a team of Soviet scientists on the first major experiment on the UNK accelerator being built at the Institute for High Energy Physics at Protvino, near Serpukhov, 60 miles south of Moscow. The NEPTUN–A experiment, scheduled to begin at the end of 1991, will study collisions of high-energy protons with spinning target protons. The main objective is to determine whether larger-than-expected spin forces persist at higher and currently unavailable energy regions. Experiments by Krisch and collaborators at Argonne and Brookhaven National Laboratories in the 1970s and 1980s posed a challenge to quantum chromodynamics, raising questions about the applicability of perturbative QCD methods at finite values of energy and momentum transfer (PHYSICS TODAY, August 1985, page 17).

The UNK accelerator is being built in stages in a 21-km ring that right now is about 75% complete. The first element will be a booster ring, consisting of conventional magnets, which is expected to be able to accelerate protons to 600 GeV by the end of 1991. A separate ring of superconducting magnets with the capability of accelerating protons to 3 TeV is to be finished around 1994. A second proton ring is to be built parallel to the first shortly thereafter. The injector is the existing 70 GeV proton acclerator.

The Michigan group is building a spin-polarized atomic hydrogen gas jet that the experimenters plan to take to Serpukhov in mid-1991. The jet will scatter high energy protons as its protons' spins reverse direction frequently. The jet relies on a temperature of about 0.4 K and a magnetic field of about 50 kG to polarize the protons' spins. The Soviet-US team also is working on a large spectrometer to detect those protons elastically scattered by the jet.

Using the UNK booster as a non-collider storage ring at around 400 GeV, the NEPTUN–A experiment will take data for 2800 hours in 1992 and 1993. Then, when the 3 TeV ring is completed, the experiment will be repeated, with the expectation of finishing in 1995. By that time the Soviets will be ready to proceed with their own series of other NEPTUN experiments, planning for which preceded NEPTUN–A. (The leader of the NEPTUN team is Vladimir L. Solovianov, and NEPTUN stands for New Experiment on Polarization at the Tunnel of UNK.)

Why not Fermilab?

Physicists from the NEPTUN experiment, which will also use the NEPTUN–A jet target, first seriously discussed cooperating on a UNK experiment with Krisch and colleagues during the September 1986 High Energy Spin Physics Symposium at Protvino. But the Michigan group reacted cautiously, partly out of uncertainty about the near-term future of newly thawing US–Soviet relations. Moreover, Michigan was conducting negotiations with Fermilab about the possibility of doing a similar polarized spin experiment on the Tevatron. But agreement was never quite reached on how to do it, and as US–Soviet relations started to warm up, the scientific and technical reasons for doing the experiment at Protvino began to look more and more attractive.

Because the effects sought in the experiment have a small cross section, a lot of running time is needed. At Fermilab the experiment would have had to be done with an extracted beam, but it works better with an internal beam, which Protvino had to offer. What's more, Protvino would have no equipment for extracting the beam during the period in which the first experiment would be done, and so the experiment would conflict with no other possible use.

The agreement to do the NEPTUN–A experiment was signed in March 1989 by Krisch, Solovianov, IHEP Director Lev D. Soloviev and Michigan President James J. Duderstadt.

The NEPTUN–A team consists of roughly 16 Soviet physicists and 16 US physicists, including four from MIT and Brookhaven National Laboratory, as well as about 12 from the University of Michigan. The MIT group is headed by atomic physicist Daniel Kleppner and is cooperating in the construction of the gas jet, which was recently successfully tested.

Other approved UNK experiments include a multiparticle spectrometer, which will take advantage of the high rate of B-meson production to look for CP violation in that system; a gluon experiment, building on current work at CERN and Protvino; and a hyperon experiment building on recent Fermilab work. Experiments for an area devoted to neutrino beams and 3 TeV on 3 Tev collider experiments are under review.

—WILLIAM SWEET

ACOUSTICAL SOCIETY ELECTS POWELL PRESIDENT

Alan Powell is the president-elect of the Acoustical Society of America, and Katherine S. Harris is vice president-elect. They will succeed the current president and vice president, Harvey H. Hubbard, a consultant for Planning Research Corporation in Hampton, Virginia, and Richard H. Lyon of MIT. The two new members of the ASA executive council are Lawrence A. Crum, associate director of the National Center for Physical Acoustics, and James E. West of the acoustics research department at AT&T Bell Laboratories, Murray Hill.

Powell received his BSc from the University of London in 1949, and went on to earn a PhD in engineering from the University of Southampton in 1953. He was a technical assistant at Percival Aircraft Co in England

Alan Powell