Superconductivity in the USA

2000 Supercond. Sci. Technol. 13 464

(http://iopscience.iop.org/0953-2048/13/5/306)

Supercond. Sci. Technol. **13** (2000) 464–467. Printed in the UK PII: S0953-2048(00)11169-8

Superconductivity in the USA

Harold Weinstock

Air Force Office of Scientific Research, 801 N Randolph Street, Room 732, Arlington, VA 22203-1977, USA

Received 20 January 2000

Abstract. This review presents a summary and explanation of US government funding for superconductivity over the past decade. It further describes unique federal programmes that are designed to stimulate industrial productivity in new technologies and that have accounted for unspecified amounts of additional R&D funding for superconductivity to commercial enterprises. Finally, several examples are given of major government programmes, of industrial programmes and of one rather large university programme.

1. Introduction

Trying to summarize the national programme in superconductivity is a more difficult task in the US than it would be in most countries. This is not simply because the US is such a large country, it is primarily because there is no specific national plan for superconductivity and no single government agency or consortium of government agencies that plans an all-encompassing programme. Each of several agencies has its own agenda; and only one, the National Science Foundation (NSF), awards research grants solely on the basis of the quality of the research proposed and of the proposed principal investigator. All other agencies are mission oriented, where, in addition to the requirement for quality, the research and/or development proposed must be responsive to a designated need of the government agency in question. Major national agencies that provide the most support for superconductivity are the Department of Energy (DoE) and the Department of Defense (DoD). Within the DoE itself there are numerous individual programmes, the largest being the Superconductivity Program for Electric Systems. However, almost as large is that of the Basic Energy Sciences Division, while the High Energy Physics and other divisions also support superconductivity. Within the DoD, most support is provided by the Defense Advanced Research Projects Agency (DARPA), the Office of Naval Research (ONR), the Air Force Office of Scientific Research (AFOSR) and the Ballistic Missile Defense Organization (BMDO). Additional research is done by the National Institute of Standards and Technology (NIST), laboratories of the National Aeronautics and Space Administration (NASA) and the National Institutes of Health (NIH). A review of research funding in major government programs will be presented.

One other factor that distinguishes the US from other countries is the large number of companies, most quite small, that are engaged in developing products and services that involve superconductivity. There are two major reasons for this proliferation of companies: one is the ready availability of venture capital, while the other is government policy that encourages business development through several imaginative programmes. Notable among these are the Small Business Innovative Research (SBIR) programme, the Advanced Technology Program (ATP) of NIST and the Independent Research and Development (IR&D) programme of the DoD and NASA. Each of these programmes will be described, and research and product development of several companies will be featured.

Finally, there are dozens of university programmes in superconductivity of all sizes, from a single faculty member to one programme that involves over 200 people. Most efforts fall somewhere between these two extremes, but generally involve only a few faculty members with their students and ‘post-docs’. At almost all universities, the ability to perform research usually is a function of a faculty member’s ability to attract funding in a highly competitive process from any of the numerous federal funding agencies. A more limited amount of research funding comes from industry, state government agencies and philanthropic individuals and organizations. Only an insignificant amount of funding for research, in almost every case, comes directly from a university’s internal operating budget. Thus, only theoretical research can be sustained without seeking some external funding. Often, where resources at a university are insufficient to sustain an intramural research effort, a faculty member and associates will work at a nearby national laboratory or university with a major programme in the field of interest. With over 200 universities in the USA that grant doctorates in science and engineering, there clearly are a large number of university research programmes, and one can safely say that superconductivity studies are carried out in over 50 of them.

2. Federal funding for superconductivity

Table 1 is a summary of US federal (fiscal-year) funding for all of superconductivity between 1990 and 1993, plus estimates of funding in 1994, 1997 and 1999. In these latter two years the estimates are quite conservative, and should be viewed as lower limits. For the most part, additional funding from SBIR, IR&D and ATP is not included. Furthermore, no

0953-2048/00/050464+04$30.00

exhaustive attempt has been to find all the superconductivity R&D and procurement in both the federal agencies listed and those not listed. There are several important points to make in viewing the funding trends in recent years. Most importantly, the bulk of the R&D funding in the last 3 years is in HTS materials and devices, certainly over 80%. By contrast, most of the procurement still is for LTS devices. It should be noted too that although no recent numbers are available for DoD procurement, it definitely is not zero. The largest apparent drop in DoE funding since 1992 is directly related to the cancellation of the Superconducting SuperCollider (SSC). In fact, DoE's commitment to HTS development has increased in recent years, principally through its Superconductivity Program for Electric Systems. There has been a real drop in funding by DoD agencies in recent years, for which there are several reasons. Most importantly, the overall DoD budget has shrunk considerably in the post-cold-war era, and almost all DoD R&D funding has been reduced significantly. There now is a sharper focus, even at the basic research level, on funding only those projects that seem to offer a response to specific military needs. This new military paradigm is coupled to a loss of the euphoria over superconductivity in which administrators at high levels considered it politically correct to start or increase funding for superconductivity. The funding for superconductivity was tracked and published annually through 1994, but afterward it became impossible to collect the needed information because it became rather difficult to identify such programmes: they rarely had superconductivity in the title. Even the NSF has no programme with superconductivity in its name. Yet, a key-word search on superconductivity (not covering all relevant grants) yielded 136 NSF research grants awarded since January of 1997, and 58 such grants since August 1998.

In summary, it can be said that while federal government funding for superconductivity has declined through the 1990s, interest in HTS development is still of considerable importance, as reflected in stable funding for specific projects. Much of the decrease in superconductivity funding is primarily a result of a decline in LTS funding in high-energy physics. The DoE has a commitment to more energy-efficient superconducting technologies in the generation, transmission and conditioning of electric power. The DoD has a commitment to improved and more secure sensors, communications systems and signal processors, as well as to more efficient motors and generators. Smaller programmes at NASA laboratories and at NIST have remained relatively stable, perhaps with only a small decline.

3. Federal programmes specifically for industry

In large measure, the summary of funding presented above does not reflect three broad programmes of governmental support to industry for research and product development. It generally is not possible to state accurately how much funding in these programmes is related to superconductivity, but a conservative estimate of their current funding for superconductivity would be in the range of $10M to $20M. The programmes are as follows.

3.1. SBIR: Small Business Innovation Research

Every federal agency that funds R&D is required by law (since 1982) to reserve a portion (currently 2.5%) of the funds it dispenses for small US-owned businesses, primarily for product development. A small business is defined as one with 500 or fewer employees. Each affected federal agency annually offers a list of topics, relevant to the agency's mission, for which SBIR proposals are sought. A small business may respond to as many specific topics as it likes, and even send the same proposal to more than one agency (although it can receive only one award for a given research topic). Successful companies receive a phase 1 award, typically up to $75k for a 6 month feasibility or design study. At the conclusion of this first contract, a company may then apply for a phase 2 award, typically up to $750k for a 24 month period to build a prototype device or system. Although there is no governmental obligation to fund phase 3, this phase is expected to involve product manufacturing, and the company is expected to describe in its phase 2 proposal how it plans to obtain phase 3 funding from private or other governmental sources. Almost every US-based superconductivity small business has received an SBIR award, usually several.

3.2. IR&D: Independent Research and Development

Every company that receives DoD and/or NASA contracts for technology development receives a type of 'bonus' in the form of extra (non-contracted) funds to carry out independent R&D of its own choosing on any project deemed relevant by the company to the funding agency's needs. Typically the IR&D funds are about 8% of the contracted amount. This gives major aerospace companies the opportunity to engage in more speculative R&D to develop improved technologies. Companies that utilize such funds for R&D in superconductivity include TRW, Northrop Grumman, Boeing and Lockheed Martin.

3.3. ATP: Advanced Technology Program

The ATP is managed by NIST to provide matching funds to companies (or consortia of companies) to develop new technologies and products. The companies may be large or small, or some combination thereof. Awardees must match government funding on a one-to-one basis, and without charging overhead. The budget for this programme has been in excess of $200M in recent years, and a typical award might be about $8M over a 5 year period. Awards for programmes involving superconductivity have gone to Dupont, American Superconductor Corporation, Illinois Superconductor Corporation, Conductus and IGC.

4. Examples of research programmes

4.1. DoE's HTS Superconductivity Program for Electrical Systems

The mission of this (now over $30M per year) programme is to work in partnership with industry to perform HTS wire and pre-commercial activities required for US companies to

Table 1. Summary of federal funding for superconductivity, 1990–1999.

Agency	FY-90	FY-91	FY-92	FY-93	FY-94[a]	...	FY-97[a]	...	FY-99[a]
Federal support for superconductivity R&D ($M)									
DoE	127.8	150.0	117.7	79.3	79.4		68.9		55.0
DoD	73.0	68.5	65.5	80.6	87.7		30.1		27.0
NSF	23.2	24.8	27.2	24.4	24.0		23.3		20.0
NIST	3.3	3.9	4.6	5.5	5.8		3.5		3.0
NASA	6.7	6.6	6.5	4.0[b]	4.0[b]		3.0[b]		3.0[b]
Total	234.0	253.8	221.5	193.8	200.9		128.8		108.0
Fed. support for purchase of supercond. devices ($M)									
DoE	18.5	39.7	133.1	16.0	21.2				
DoD	18.0	30.0	NA	NA	NA				
Total	36.5	69.7	133.1	16.0	21.2				

Not included: other federal agencies, SBIR, ATP and IR&D.
Sources: Federal Research Programs in Superconductivity, June 1994, and private communications.
[a] Estimates by agency personnel.
[b] Estimates made by the author.

commercialize HTS electric power applications. Its specific strategic goals are to (1) achieve HTS wire with 100× the current capacity of copper, and (2) complete prototype demonstrations of HTS electric power equipment such as motors, current controllers, power cables, transformers and generators. This involves a partnering among seven electric utility companies, 20 manufacturers, seven national laboratories (six of DoE's plus NIST) and 23 universities. One especially notable segment of this programme is a superconducting cable project that integrates a three-phase, 120 m HTS cable into an existing utility network for continuous operation at 2400 A and 24 kV. This involves a joint effort of the Pirelli Cable Corporation, Electric Power Research Institute (EPRI), American Superconductor Corporation (ASC), Detroit Edison, Lotepro (a wholly owned subsidiary of Linde AG that supplies refrigeration systems) and Los Alamos National Laboratory. Installation of the cable has just begun, with operation scheduled to begin in 2000, and with testing and monitoring scheduled to continue through 2002.

4.2. DoD programmes

Both the air force and navy have strong interests in the development of long lengths of HTS wires with high current-carrying capacity, principally to make compact, efficient motors and generators. Because of this common interest with DoE, there is a strong interaction with the DoE programme just described. The navy's principal interest is to develop motors for the delivery of ship power, while the air force is interested mainly in generators and magnetic energy storage for air- and space-power systems. These two military services and DARPA also have invested substantially in R&D for (mostly passive) microwave components and systems. Among the most visible of these programs is the navy's High Temperature Superconductivity Space Experiment (HTSSE), which was designed to demonstrate the viability and survivability of HTS electronic components and systems in space. After a delay of about 2.5 years, a complex of HTS (mostly vendor-supplied) sub-systems was launched on 23 February 1999. Initial indications of data from space indicate no obvious degradation in operating characteristics. A multi-year DARPA program is currently concluding its final phase, which has included packaged HTS components with cryocooler and support electronics, a stable local oscillator (STALO) for cryo-radar and a 32-element switchable filter bank.

4.3. Industry profiles and programmes

4.3.1. IGC. IGC is the largest US company in the field of superconductivity. Founded in 1971 with 15 employees, today there are about 600 employees and annual sales in excess of $100M. Its major products are superconductive (LTS) magnet systems for MRI applications. It produces the NbTi wire that is utilized in such magnets at its Waterbury, CT facility, which features the world's longest wire draw-bench (of over 60 m). It is active as well in the manufacture of BSCCO tape, which is then incorporated into HTS transformers and current controllers among other products. Most recently it has made significant progress in a YBCO coated-conductor technology via MOCVD.

4.3.2. American Superconductor Company (ASC). ASC is an example of a company that was founded specifically to develop HTS-based technology in 1987, with a specific focus on developing wire for power industry applications. By 1999, $180M had been invested in HTS applications such as the Detroit Edison project mentioned earlier and the magnet coils for a 1000 HP motor built by the Reliance Electric Company, to be followed shortly with the development of a 5000 HP motor. Currently, ASC has about 240 employees and has expanded to include LTS systems through its acquisition of Superconductivity, Inc. in recent years.

4.3.3. Superconductor Technologies, Inc. (STi). STi was founded in 1987, grew rapidly to 30 employees within 2 years and experienced slow growth to 65 employees over the next 8 years. In the past 2 years STi added manufacturing, marketing and sales, so that 140 people are now employed. Its early growth was provided principally by venture capital and a public stock offering. Until now, total financing from equity equals \$52M. Its principal products are HTS RF and microwave filter systems. Their trademarked SuperFilter products have been field tested by more than 30 cellular service providers, including nine of the ten leading US firms. These have improved receiver sensitivity by about 5 dB, extended range by 30% to 80%, increased revenues by over a factor of two, reduced drop-calls by 40% and extended handset battery life.

4.3.4. HYPRES. HYPRES was established with venture capital funding in 1983, principally to develop the world's fastest sampling oscilloscope using Josephson-junction-based technology. While this product came to market over the following 3 or 4 years, it was not a great commercial success and was dropped. Currently, its staff of 20 provides a foundry service in niobium-based LTS electronics technology. As an example of the importance of this service to the community, about 70% of the LTS digital electronics results reported at the 1998 Applied Superconductivity Conference came from HYPRES chips. Among its products are a Josephson array primary voltage standard (both chips and complete systems) and SQUID amplifiers. Many of its current R&D is funded by the DoD. One of the largest, valued at \$1 950 000 over 24 months, is a phase 2 SBIR project to develop an RSFQ-based memory technology. Managed by AFOSR, funds come from BMDO, the National Security Agency and venture capital.

4.3.5. Neocera. Neocera is a 10 year old company providing microelectronics and sensor-based instrumentation and which has materials expertise in thin-film development and production. From its modest beginning in an industrial research park on the edge of the University of Maryland campus, it has grown recently to occupy over 1800 m^2 elsewhere and to generate an estimated \$10M in revenue with 43 employees by the end of 1999. Its current projections call for revenues to exceed \$21M and almost 100 employees two years hence. The recent and projected growth is based primarily on two major new products introduced in 1999. One, its trademarked MAGMA-C1 scanning SQUID microscope has proven useful in detecting short circuits in multi-chip modules, and a number of units have been ordered by electronics industry manufacturers.

4.4. University research centres

While some form of superconductor research is carried out at dozens of US universities, sometimes with just a single faculty member, there are about 10 to 20 universities which have much more extensive programmes or research centres devoted primarily to various aspects of superconductivity. Funding for these comes mostly from the federal agencies mentioned earlier, but some programmes receive significant funding from state or local governments, industry and private benefactors. Three so-named superconductivity centres can be found at the University of Wisconsin, University of Maryland and University of Houston, while some other major programmes are at Stanford University, the University of California at Berkeley and at San Diego, the University of Illinois and MIT. The largest centre for superconductivity research in the US is the Texas Center for Superconductivity at the University of Houston (T_cSUH). Directed by Paul Chu since its inception over 11 years ago, T_cSUH employs a total of 261 people (or about 160 full-time equivalents). In the past year it received \$6.7M in direct funding from the state of Texas, which has been augmented by other state funds, federal agencies, industry and private foundations. One foundation, specifically established to aid T_cSUH, has an endowment of over \$20M.

5. Summary

An article of this length can never do justice to the vast and diverse enterprise labelled superconductivity in the USA. The theme, therefore, has been to relate how the US programme varies from that of other countries, to provide a rough estimate of government funding, and to highlight some of the principal research programmes and especially companies that sell superconductor-based products—this last being especially characteristic of the US. Unlike many western European countries and Japan, the US has no centrally directed government programme: it has a large and diverse set of small companies that receive financial support from focused federal and state programs, venture capitalists, stock purchasers and from the products they sell. Finally, it has an extraordinarily large number of well equipped university research centres that attract both high-quality domestic and foreign students and 'post-docs'.

Acknowledgments

The author wishes to thank the following individuals for their aid in supplying input for this article: Jim Daley, Bruce Strauss and Bill Oosterhuis (DoE); Frank Patten, Don Gubser and Marty Nisenoff (DoD); Dick Harris (NIST); Alan Kleinsasser (JPL/NASA); Clive Perry (NSF); V Selvamanickam (IGC); Bob Schwall and Peter Herz (ASC); Bob Hammond (STi); Lee Knauss (Neocera); Elie Track (HYPRES); John Talvavacchio (Northrop Grumman); Paul Chu and Sue Butler (T_cSUH). The author's apologies are extended to all other people, institutions and agencies whose contributions have been omitted either due to ignorance or lack of space. For those organizations and programmes that were cited, the author also must apologize for the brevity of the citations.