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Government Programs on Advanced Technology and Manufacturing Techniques: Comments on U.S.A., Japan, and Europe*

W. Murray Bullis

Abstract

For many years the U.S. semiconductor industry benefited significantly from government-financed technology developments, principally in the areas of defense and space. In recent years, however, government policies and actions have tended to reduce both the level of direct government support of device research and the incentives for private sector investment in this area. At the same time intense competition from foreign producers and major government-financed programs to advance integrated circuit technology, especially in Japan, have threatened the U.S. technological lead in semiconductor device technology. These international challenges are being viewed by many in the industry as requiring responsive efforts by the Federal Government. One such response could be in the form of technological cooperation between government and industry in areas where in industry may desire assistance in solving generic design, manufacturing, or testing problems. The Department of Commerce is considering new mechanisms for carrying out such cooperative efforts. These mechanisms are described following a brief review of other past and present government programs in advanced technology and manufacturing techniques — both here and abroad.

Key Words: Cooperative technology; electronics; foreign competition; integrated circuits; semiconductor technology; VLSI.

The influence of foreign competition on the present and future health of the U.S. semiconductor industry is receiving an increasing amount of public attention at all levels of government and commerce. This is an extremely complex problem which encompasses a wide range of economic considerations and business strategies in addition to the technological issues which are the subject of this session. Our concern at the National Bureau of Standards, of course, is also with technological

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issues. We have long been associated with the semiconductor device, materials, and equipment industries through our program to develop semiconductor measurement technology.

The important economic and business problems — insufficient risk capital, unequal tariffs, non-tariff trade barriers, export controls, and government regulatory climate — have been apparent to all. Although the technological aspects of the foreign competition problem were not quite so clear, it is the Japanese government's major investment in development of VLSI technology which precipitated a good bit of the public attention [1-3]. Therefore we set out to study what the technological aspects might be and what Government actions might be proposed in response.

In considering these questions, it is instructive to gain a bit of historical perspective. In this country the association between the Federal Government — especially in the areas of defense and space — and the semiconductor device industry has been a significant factor in the rapid development of new technologies. The extensive literature on this topic, especially that related to integrated circuit development, has recently been reviewed and summarized by Asher and Strom of the Institute for Defense Analyses [4].

For the purposes of the present discussion, there are several important points to be considered. First, the Government has provided considerable support for semiconductor research and development. The Semiconductor Industry Association (SIA) estimates that various branches of the Government have supported nearly 30 percent of the total semiconductor R & D effort between 1958 and 1976 either directly or in conjunction with development of equipment or systems (see table 1) [5]. In the integrated circuit field, the direct Government support of applied research was nearly $30 million in the six years immediately following their invention (see table 2) [6]. Second, in the years from 1958 through 1974 the military and space efforts of the Federal Government, especially through the Minuteman Missile program, provided both the design impetus and the initial market for integrated circuits. This is a factor which may be even more important than the direct R & D support [4,7]. Third, through various contracts for production preparedness, the U.S. Army, Air Force, and Navy supplied about $36 million to industry to build production equipment at three critical stages in the development of semiconductors and integrated circuits [7].

Fourth, commercial interests, especially computers, also played a key role in the development of the American semiconductor industry. For example, in the early sixties, IBM was the largest single consumer of semiconductor devices [7].

Finally, and most significant for the present discussion, the level of Government funding for semiconductor R & D has declined in recent years. For example the SIA estimates that the average annual direct R & D support level between 1970 and 1976 was less than half the average annual level between 1958 and 1969 [5]. The decline is vividly displayed in figure 1, a plot of DoD contractural funding for exploratory development of electron devices which, although it includes devices other than semiconductors, illustrates the trends [8]. Note that the dollar increases during the last decade have only been sufficient to maintain level activity (in constant dollars).

The Japanese semiconductor industry has also enjoyed a long and fruitful relationship with its government. The semiconductor industry in Japan generally has lagged that in the United States. Through the early and middle 60's Japanese production was principally discrete devices for consumer electronics; integrated circuit production did not begin until 1968. Government electronic component programs date from 1955; semiconductor-related programs have been underway for more than a decade (see table 3). These programs have been primarily oriented toward commercial applications with heavy emphasis on information processing and computers.

The Japanese VLSI Project was started in March 1976. This four-year program has a total budget of about 70,000 million yen which translates at current exchange rates to over $300 million [9]. About 40 percent of the funding is supplied by the Japanese government while the remainder is supplied by the five participating companies. The VLSI Cooperative Laboratories, which are expected to absorb about one-fifth of the resources available to the Project, carry out the more basic aspects of the work while two other laboratories, the Computer Development Laboratories and the NEC-Toshiba Information Systems Laboratories, apply the research to more specific developments. The Project is intended to develop the various technologies necessary to produce very large scale integrated circuits (see table 4). The objectives are divided in such a way that the Cooperative Laboratories work on microfabrication and crystal technology development in their entirety and the fundamental parts of the development of process, test and evaluation, and device technologies. The two applied laboratories carry out the design technology work and the more product oriented work on the last three technologies. Finally, the five individual companies which participate in the Project develop specific circuits and hardware for use in the computers which they will manufacture.

The thrust of the Project is the development of advanced technology which, if successfully developed and applied, would enable the Japanese to attain a significant world-wide position in semiconductor technology for computer applications. Although the stated intention is to publish the advances achieved in the open literature, the advantages accruing to those actually carrying out the work are well known.

The situation in Europe is substantially different. A report prepared under the sponsorship of the German, British, Dutch, and French governments indicates that with the possible exception of Philips there is no large and successful European producer of integrated circuits [10]. It would appear that the Europeans have not yet been able to come up with a collective solution to the problem of competition with the United States and Japan in the integrated circuit field. The European Economic Community is in the process of developing a comprehensive plan for European activity in this area [11], but this plan appears to be a long way from implementation.

Individual governments have responded to this situation in various ways. In 1974, the West German Ministry for Research and Technology began a five-year program on electronic components intended to open up particularly promising areas, especially in microelectronics. The program, which had a planned expenditure of nearly DM 300 million, was undertaken as a response to the government support and procurement contracts granted in other countries, particularly the United States and Japan, which have, in West Germany's view, provided those countries with a leading position in microelectronics. Originally this program covered work in integrated circuits, optoelectronic components, materials development, and semiconductor production methods, as well as basic research on new components. Because of the continuing volatility in prices and technological advances, this program has been extended for two or three more years and has been expanded to increase the emphasis on applications, especially watches and appliances. In addition, the West German government has a variety of programs which will provide significant markets for electronic components [12]; these include improvement and enlargement of the telecommunications systems of the German Post Office, an electronic data processing promotion program which will provide nearly DM 300 million per year to the German computer industry for research and development, and major expenditures for new defense equipment.

The British government has long supported advanced research and development in the semiconductor device field, primarily through the military laboratories and the British Post Office. These programs have generally been highly specific to a particular device, advanced technology, or application. They have frequently come at critical times in the development of various technologies. For example, beginning this year, the British expect to spend over £ 1 million to improve electron beam fabrication capabilities in the U.K. [13]. On a larger scale, the U.K. Department of Industry is expected to announce soon a major five-year program to assist the British IC industry by assuring local sources of circuit design and LSI and VLSI manufacturing expertise [14]. This program is estimated at £ 75 to 100 million, split between government and industry in a way yet to be decided.

France has undertaken a 600-million-franc, 5-year program to bolster its IC industry [15]. One goal of this program is production of circuits with 1-μm feature dimensions by 1983 [16]. This R & D effort is to be supplemented by research centers of multi-national companies attracted by the French market. The latter approach is similar to that used by a variety of private European companies to obtain additional advanced technology. Many such companies, especially Philips and Siemens, have been active in acquiring full or partial control of U.S. semiconductor houses. The multi-national nature of the semiconductor business, especially when the controlling interests are not United States companies, provides additional avenues for the uncontrolled diffusion of American semiconductor technology throughout the world.

So much for historical prespective. Where do we go from here? Clearly, the industry desires changes in trade, regulatory matters, and tax laws which would permit it to compete more effectively in international markets and to attract the necessary risk capital for expansion. The question remains as to whether the industry desires additional Government assistance in technological areas. During the past year Jud French, Director of the Bureau's Center for Electronics and Electrical Engineering, has discussed these matters with many industry leaders. He found universal agreement that there is indeed a technological element to the problem of international competition and widespread interest in exploring the possible benefits and problems of a cooperative Government-industry response. Although there were mixed feelings as to the type of cooperation desired, there was general agreement that next generation manufacturing procedures would be too costly in capital equipment and associated infratechnology for most companies to develop independently. This is further borne out by the variety and depth of technology exchange agreements which are being entered into at an increasing rate by many companies of all sizes.

One common response was made by all: Government-industry cooperation is most desired in connection with basic manufacturing technology — or infratechnology — which undergirds the industry. This infratechnology is for generic, industry-wide application. It includes new and more definitive basic data, principles, test methods and associated techniques, and equipment for common use throughout the industry. It may be used in development and design, in procurement and evaluation of manufacturing materials, in carrying out and controlling manufacturing processes, in specification and test of finished products, etc. Government support of basic infratechnology both avoids unnecessary duplication of expenditure for non-proprietary, commonly-held information and technology and frees industrial funds for the development of new and higher quality proprietary designs, processes, equipment, products, and applications.

Such an approach, though it sounds strangely like the Japanese VLSI Project, differs considerably from traditional practices for Government support of the semiconductor industry in the United States. Nearly all of the support for semiconductor R & D has been directed either at very basic research activities or toward development of specific devices and circuits. No mechanism is being effectively utilized for the support of manufacturing science, and that fundamentally is what development of infratechnology is all about.

One possible mechanism might appear to be the Defense Department's Manufacturing Technology Program. The semiconductor device industry has conducted quite a number of projects under this program. However, as V. J. Adduci noted last year [17], the funds available for manufacturing technology appear to be designated exclusively for Manufacturing Methods and Technology (MM&T) projects and thus are denied for

R & D use even though the regulations provide for a category called "R & D Mantech". Adduci strongly recommended that manufacturing technology funding be appropriated specifically for R & D efforts. Even in the MM&T activities, special efforts must be made if the results are to be broadly used. Adduci pointed out that the documentation on completed MM&T projects has generally been inadequate to permit another organization to implement the newly developed technique or capability. He emphasized that this type of information must be specifically described and requested in the Request for Proposals and that adequate time and funding must be provided to permit its preparation.

As another example of the difficulty of conducting manufacturing R & D, consider the program on integrated circuit reliability and manufacturing science, which the Navy attempted to establish five or six years ago. This was to be a long range research program with emphasis on just those manufacturing techniques needed for VLSI. Following an initial survey phase, this promising program unfortunately failed to receive adequate support.

At the National Bureau of Standards, we have had first hand experience with this problem. For more than ten years, we have been conducting a research and development program in a single area of the infratechnology spectrum: measurement technology for semiconductors, applicable both in the marketplace and on the production line. This program covers the range from applied research on fundamental material properties to the development and documentation of specific measurement instrumentation and techniques. It has already had significant impact in the areas of silicon resistivity measurements, wire bonding, thermal characterization of transistors, leak testing of hermetic devices, test structure design and development, and dimensional metrology for photomasks. For the last five years, major funding for this program has been supplied by the Defense Advanced Research Projects Agency (ARPA). This funding which, of course, emphasizes the more research oriented aspects of the program is now decreasing and is scheduled to terminate next fiscal year in accordance with the original plan. ARPA's policy does not typically permit support of long term programs. Its goal is to stimulate and demonstrate technical advances and then spin them off. Various avenues within the Defense Department are being explored to obtain alternative sources of funding which will permit the program to continue with its present broad scope and generic nature. To date we have not had great success, especially with those parts of the program relating to the development and implementation of instrumentation and techniques for use in manufacturing.

So the environment for programs on manufacturing science for integrated circuits at the present time does not appear to be particularly favorable. The Department of Commerce, of which the Bureau is a part, recognizes the problems and has asked for the opportunity to determine the desirability and feasibility of cooperative programs between industry, universities, and Government to aid industry, through, for example, development of appropriate infratechnology. As presently envisaged, the

Bureau would play a key role in establishing and promoting such cooperative efforts. As now conceived, the operating principles would include these:

- Users must recognize that a problem or opportunity exists and seek collaboration; that is, the industry must want the Government to participate and must take a lead role in defining the problem and the approach to a solution.

- Each project must be planned and implemented collaboratively among Government, technology producers, technology users, and the public.

- There must be a clear rationale for Federal involvement in each project and a plan for ending such involvement must be built into the plan at the outset.

- The program must be open to all interested parties.

- Provisions for appropriate access to the output must be developed.

- In view of finite funding, tasks under the program must leverage existing institutions, programs, funding, and capabilities, and a systematic process must be used for analyzing prospective activities so that choices can be made rationally and realistic program limits can be set.

The proposed operating process contains a number of critical steps, ranging from the initial identification of the problem or opportunity to evaluation of the success of the responsive task. Discussion of these in sufficient detail for a clear understanding is much too lengthy for this brief preview. Instead, it is appropriate to re-emphasize the first principle of the program: That the initiative is left to the beneficiaries of the technology, that is to those who feel the desire to collaborate in developing new generic technology, or in strengthening or establishing mechanisms for developing technology in cooperative ways.

In the development of cooperative efforts, the Department would look first to existing institutions in the private sector (trade associations, consortia, research institutes, and universities) as participating groups and would help in problem definition and in the solution of the problem. This is not to be simply a grant program, however; industry, universities, and government must share in some way in the support, responsibility, and activity.

This new concept is just in the study stages, and, as of today, no program has been authorized or funded by Congress. We plan to involve industry in the study and to advise the industry of our plans as they develop both informally and eventually through a Federal Register notice.

Professional or trade organizations are good mechanisms for bringing the industry's needs to the attention of the proper people in Government: Dr. Jordan Baruch, Assistant Secretary for Science and Technology, in the

Department of Commerce, or Dr. Howard Sorrows, Technology Advisor to the Director of NBS, who is responsible for developing cooperative technology concepts at the Bureau. They will welcome views and recommendations for joint technical efforts. They will welcome, also, advice and suggestions concerning the operation of such cooperative efforts which can be considered during the study phase.

Remember also, that NBS already has a program on semiconductor technology underway, and it is not too soon for the semiconductor industry to make its needs known to the Bureau with respect to this existing program. Many mechanisms already exist for cooperation betwen NBS and industry, and many industries have already made use of them in solving problems ranging from gage block stability to improved dental and roofing materials; so exploration of mutual interests is likely to be beneficial.

These are not the only approaches appropriate for meeting the international challenges. For example, the National Science Foundation has established a submicron facility at Cornell for the use of academic and industrial researchers. The Defense Department has reversed its hands-off policy on development of integrated circuits and is establishing, beginning next fiscal year, a five-to-seven year program to develop very high speed integrated circuits with submicron geometry. And the Department of Energy is exploring university-industry collaborations to broaden the technology base for photovoltaic-solar cells. In any event, the industry clearly will have a key, independent role to play.

Whatever approaches are chosen, however, we must decide what we want to do and get on with it if we are to successfully meet the present challenges. The point is admirably made in the editorial in the April 1978 issue of *Instrument and Apparatus News* which ends in the following way:

> "But the question of whether or not the Japanese have some sort of edge in the international marketplace is really not crucial. Whatever edge they may have, they are likely to keep. What is crucial to us is that we get our own house in order. We should develop and refine our own "edges' so that we will once again be the dominant force in the world marketplace. Let's admit once and for all that the Japanese are not doing anything underhanded or unethical. Let's admit that they are just playing the game a little better than us in some areas. And, finally, let's do something to put ourselves back on top." [18]

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Table 1 — Estimates of U.S. Semiconductor R & D Support from 1958 through 1976

Direct Government Support	$ 350 M	14.5 %
From Product Sales to Government	$ 352 M	14.6 %
Industry Funded	$1713 M	71.0 %

Source: Semiconductor Industry Association, March 1978.

Table 2 — Early U.S. Government Support of Integrated Circuit R & D

Year	DoD	NASA	Sum
1959	$ 3.12 M		$ 3.12 M
1960	$ 3.79 M		$ 3.79 M
1961	$ 6.03 M	$0.14 M	$ 6.17 M
1962	$ 5.11 M	$0.11 M	$ 5.22 M
1963	$ 5.23 M	$0.24 M	$ 5.47 M
1964	$ 4.18 M	$1.36 M	$ 5.54 M
Total	$27.46 M	$1.85 M	$29.31 M

Source: Asher and Strom [6].

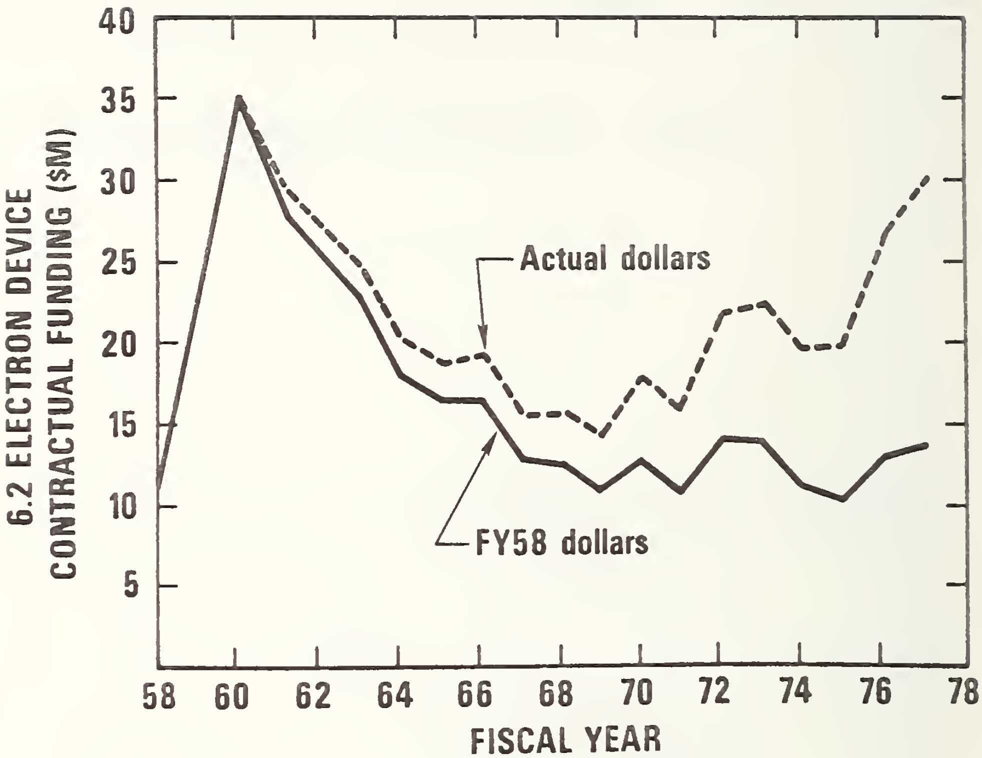

Figure 1. Defense Department contractural funding for exploratory development of electron devices.

Table 3 — Japanese Government Semiconductor Programs

1966-71	Super-High Performance Computer System		$ 28 M
1971-78	Pattern Information Processing System		$ 97 M
1973	Process Technologies Program		$ 20 M
	Silicon gate	Hitachi	
	CMOS	Toshiba	
	Bipolar digital	Fujitsu	
	NMOS	NEC	
	Industrial linear	NEC	
1975-77	NTT Memory Development		$ 67 M
1976-1980	VLSI Project		$310 M[a]
	VLSI Technology Research Association Cooperative Laboratories		
	Computer Development Laboratories (Fujitsu, Hitachi, Mitsubishi)		
	NEC-Toshiba Information Systems Laboratories (NEC, Toshiba)		

[a]Total budget; split 40% government, 60% industry.

Table 4 — VLSI Technology Research Association R & D Items

1. Microfabrication Technology
2. Crystal Technology
3. Design Technology
4. Process Technology
5. Test and Evaluation Technology
6. Device Technology

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For many years the U.S. semiconductor industry benefited significantly from government-financed technology developments, principally in the areas of defense and space. In recent years, however, government policies and actions have tended to reduce both the level of direct government support of device research and the incentives for private sector investment in this area. At the same time intense competition from foreign producers and major government-financed programs to advance integrated circuit technology, especially in Japan, have threatened the U.S. technological lead in semiconductor device technology. These international challenges are being viewed by many in the industry as requiring responsive efforts by the Federal Government. One such response could be in the form of technological cooperation between government and industry in areas where the industry may desire assistance in solving generic design, manufacturing, or testing problems. The Department of Commerce is considering new mechanisms for carrying out such cooperative efforts. These mechanisms are described following a brief review of other past and present government programs in advanced technology and manufacturing techniques — both here and abroad.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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