**PLAN FOR ADVANCED MICROELECTRONICS PROCESSING TECHNOLOGY
APPLICATION**

FINAL REPORT

Principal Investigator: Allen N. Goland

October 1990

**A Research Agreement between New York State Science and
Technology Foundation and Associated Universities, Inc.**

NYS STF Contract 88029

APPLIED PHYSICS

DEPARTMENT OF APPLIED SCIENCE

**BROOKHAVEN NATIONAL LABORATORY
UPTON, LONG ISLAND, NEW YORK 11973**

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Final Report

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Final Report

Reference: Research Agreement between New York State Science and Technology Foundation and AUI covering "Plan for Advanced Microelectronic Processing Technology Applications" (BNL Account 87508) (NYS STF Contract 88029).

I. Overview

Funding under the above-named research agreement began for one year in July 1989. A no-cost extension through September 1990 was granted for the purpose of completing the task of preparing this final report. The progress described in the report was co-funded by a technology-transfer grant from the Department of Energy. Brookhaven National Laboratory has a very active Office of Technology Transfer, and the availability of its resources to the principals in this research effort was critical to the successful completion of the required tasks.

The ultimate objective of the tasks described in the research agreement was to identify resources primarily, but not exclusively, within New York State that are available for the development of a Center for Advanced Microelectronics Processing (CAMP). Identification of those resources would enable Brookhaven National Laboratory to prepare a program plan for the CAMP. In order to achieve the stated goal, the principal investigators undertook to meet with key personnel in relevant NYS industrial and academic organizations to discuss the potential for economic development that could accompany such a Center and to gauge the extent of participation that could be expected from each interested party. Integration of these discussions was to be achieved through a workshop convened in the summer of 1990. The culmination of this workshop was to be a report (the final report) outlining a plan for implementing a Center in the state.

As events unfolded, it became possible to identify the elements of a major center for x-ray lithography on Long Island at Brookhaven National Laboratory. The principal investigators were then advised to substitute a working document based upon that concept in place of a report based upon the more general CAMP workshop originally envisioned.

Following that suggestion from the New York State Science and Technology Foundation, the principals established a working group consisting of representatives of the Grumman Corporation, Columbia

University, the State University of New York at Stony Brook, and Brookhaven National Laboratory. Regular meetings and additional communications between these collaborators have produced a preproposal that constitutes the main body of the final report required by the contract.

Other components of this final report include the interim report and a brief description of the activities which followed the establishment of the X-ray Lithography Center working group.

The next step will be to secure funding that will enable the working group to prepare a complete conceptual design study for the proposed Long Island Center for X-ray Lithography. One immediate source of cofunding is the NYS Department of Economic Development through its Regional Economic Development Partnership Program. The working group is actively pursuing that avenue at this time.

Funding for implementation of the plan in the completed conceptual design study will be sought from appropriate Federal and New York State agencies, and from industrial concerns which would provide co-funding. Two examples of Federal agency targets are DARPA and NIST/Advanced Technology Program.

II. Interim Report Covering Period from 1 July 1989 - 31 January 1990.

Interim Report

The Development of a Program Plan for a Center for Applied Microelectronics Processing (CAMP)

Background

A series of workshops was held at Brookhaven National Laboratory beginning in 1986 on the subject of X-Ray Lithography. The purpose of these workshops has been to examine various key issues associated with the technology of x-ray lithography, and to identify actions which might be taken in support of the United States microelectronics industry.

In the intervening years, the Defense Advanced Research Project Agency (DARPA) has committed funds for a technology-transfer effort at Brookhaven to design and build a storage ring with superconducting magnets in association with industrial subcontractors. This ring is to be optimized for x-ray lithography.

One of the workshops was convened to define the scope and cost of a prototype preproduction facility built around a dedicated and optimized electron storage ring. The projected magnitude of such a project suggested to Brookhaven staff members that an effort should be made to develop a program plan for a Center for Applied Microelectronics Processing to organize and operate this advanced facility somewhere in New York State region. Discussions with program managers in the Technology Transfer Office of the Department of Energy (DOE), and with the Executive Director of the New York State Science and Technology Foundation and his staff led to a cofunded program to accomplish that task.

As often happens in such instances, the funding from the two agencies was not precisely in phase, the DOE funding arriving first. Therefore, some of the events described in this interim report were supported by the DOE funds at first and others were jointly supported after the start of State funding. As this project has been a part-time activity of the principals, the phased funding actually provided a flexibility in the timing of visits around the State that made it easier to accommodate the schedules of those visited.

Due to the accelerated pace of events relating to x-ray lithography that occurred toward the end of the first six months of this contract, the important questions triggered by this contract research were addressed in the second half of its funding period. They will be treated in the final report which will focus on a white paper that discusses the rationale for a Center for X-ray Lithography on Long Island, NY.

Progress in Period Ending 1/31/90.

Formation of Local Panel.

An informal panel of Brookhaven staff members was formed at the outset to discuss the best approach to the tasks set forth in the DOE and New York State contracts. The panel consisted of approximately 10 people with a variety of backgrounds including electron microscopy, physical chemistry, engineering, physics and microelectronics.

The panel concluded after several discussion meetings, that in the early stages, the efforts of the principals should be aimed at identifying and meeting with potentially active participants in a future Center for X-ray Lithography. In accordance with the intent of the contract these participants were to be selected from within or near New York State. This activity was expected to continue throughout the life of the contract, but by the end of the period covered in this interim report a number of persons had been visited at least once.

List of Persons Visited

Philip Lewis, Chairman
Department of Computer Science
SUNY at Stony Brook, NY

Alan Wilson, Director
X-ray Lithography Program
IBM Watson Research Center, Yorktown Heights, NY

Robert Hill, Manager
Advanced Lithography Systems Department
IBM, East Fishkill, NY

Joseph Calviello, Senior Research Scientist
Eaton Corporation, AIL
Melville, NY

Edward Wolf, Director
National Nanofabrication Facility
Cornell University

Walter Gibson, Physics Department
SUNY at Albany

Richard Delasi, Director
Corporate Research Center
Grumman Aerospace Co.

William Brinkman, VP for Physical Research
AT&T Bell Laboratories
Murray Hill, NJ
(Phone discussion)

Elliot Cohen
MMIC Program contact
DARPA

Richard Osgood, Jr., Director
Microelectronics Sciences Laboratories
Columbia University

Arjun Saxena, Director/Al Jordan, Deputy Director
Center for Integrated Electronics
Rensselaer Polytechnic Institute
Troy, NY

Kenneth Pickar/Richard Alben
General Electric Corporate R&D Center
Schenectady, NY

Additional organizations were targeted as a result of these contacts and input from the State Science and Technology Foundation. For example, some of those companies and other institutions identified for future visits or phone conversations were Hampshire Instruments, Kodak, Xerox, Corning Glass, Alfred University, Clarkson University, and Rome Air Force Base.

Consideration of an Interim Workshop.

Some thought was given to an interim workshop to identify important problems and centers of technical excellence that could address those problems. However, it was concluded that based upon cost and lead time necessary to guarantee a successful effort, such a workshop would not be cost effective. A fifth BNL workshop on synchrotron x-ray lithography had been scheduled for November 16-17, 1989, and it was anticipated that this meeting would provide an important yardstick of interest in the concept of an X-ray Lithography Center. Members of the CAMP advisory panel were the organizers of the workshop, and were invaluable to us subsequently in formulating plans for the second half of the funding period.

The Report of the Fifth Workshop on Synchrotron X-ray Lithography is appended to this report as supplementary information. The recommendations of the workshop attendees strongly influenced the direction of the subsequent planning for the Center project.

The consensus of the local BNL committee was that the findings and recommendations of the 5th Workshop reflected the thinking which is expressed in the DOE/NYS proposal for a CAMP. Therefore, it was decided to move ahead as briskly as possible with the tasks outlined in the Statement of Work.

Planning sessions began for the CAMP workshop that would be held in the late spring or summer of 1990. Additional contacts in the lithography field were identified and plans for subsequent visits were made. Discussions were held with Brookhaven management to ensure a unified approach to the CAMP concept.

Because the Grumman Corporation has been involved in the technology transfer of accelerator expertise from BNL through the DARPA-funded superconducting x-ray ring project, conversations were held several times with Richard Delasi, Director of Grumman Corporate Research. An effort was made to discover Grumman's plans for subsequently becoming involved in the applications of the compact x-ray rings they hope to build and market. Grumman is an important technical resource on Long Island, and would be able to bolster and enhance the proposed Center R&D program.

No clear picture of Grumman's plans arose from these talks, but it was determined that the company would be taking a close look at its

options. It had closed its GaAs facility in Princeton, NJ recently and was fashioning a new plan for the clean-room environment that became available when the Princeton operations shut down. A clean room would be a valuable asset in the initial startup of an XRL Center, and the thought was expressed to Grumman that it should consider placement of the clean room at the NSLS. A decision was to be made at a later date within the Grumman Corporation.

Another approach to x-ray lithography is based upon the use of a laser-driven plasma point source. Hampshire Instruments of Rochester, NY is the chief proponent of this technology and we visited Robert Frankel there on 1/26/90. We learned that the company is making progress although its source intensity needs to be increased for production work. The company is split equally between New York State and Marlboro, Massachusetts. In the Rochester plant, source development and manufacturing are conducted, while the Marlboro facility houses a clean room and a prototype source. Mask development, engineering design and customer interactions take place in Marlboro.

Although Hampshire Instruments is developing an alternative source concept, the company would be interested in those aspects of the x-ray lithography technology which are common to all in the field, namely such items as mask development and photoresists.

Plans for Second Half of Contract Period.

The major effort in the second half of the contractor period was expected to be planning and convening a workshop whose report would constitute the final task. Preliminary plans were drawn early in 1990, and an organizing committee was identified. The first meeting of this committee was scheduled for late March. Representatives from RPI, Karl Suss, AT&T, IBM, and Columbia University were included.

Additional time was scheduled for further visits including one to the Science and Technology Foundation Offices in Albany in order to make a verbal report and confirm workshop plans.

The final report, which is intended to present a plan to New York State for how to proceed with the establishment of a Center relevant to

x-ray lithography and to other advanced photon-assisted materials processing, will be prepared during the summer of 1990.

Allen N. Goland
Project Director

- III. Activities during the Period 1 February 1990 and 30 September 1990.
(Note: a no-cost extension from 30 June 1990 to 30 September 1990 was granted.)

During the second half of the contract period, activities were directed towards the organization of a workshop whose report would become the main element of our final report. To this end, the local committee developed preliminary plans during February and March. A workshop organizing committee including outside members was established and convened at Brookhaven on March 20, 1990. The members of this committee were:

Mr. Keith Copper, Karl Suss America, Inc.
Professor Arjun Saxena, Rensselaer Polytechnic Institute
Dr. Richard R. Freeman, AT&T Bell Laboratory
Professor Richard Osgood, Jr., Columbia University
Dr. Mark Barton, IBM
Mr. Jules Godel, BNL
Dr. William Marcuse, BNL
Dr. Gwyn Williams, BNL
Dr. Allen Goland, BNL, Chairman

The committee decided that the most effective way to reach the appropriate high-level participants for the workshop was to prepare a brief paper outlining a preliminary plan for an Eastern Regional Micro-processing Applications Center focused on x-ray lithography. This brief plan is included on pages 11-14.

Before moving ahead with the proposed workshop, discussions with the representatives of the New York State Science and Technology Foundation were deemed necessary. Accordingly, on April 24, 1990 a meeting was convened in Albany with Dr. Graham Jones, Executive Director of the Foundation and Dr. Vernon Ozarow, Manager of University/Industry Programs for the Foundation. A full morning of discussion led to the unanimous decision to move ahead with the already-organized coalition of Grumman, Brookhaven, Columbia and SUNY/Stony Brook to formulate a plan for an X-ray Lithography Center. This action would be regarded by the Foundation as an alternative to the workshop originally spelled out in the contract Statement of Work.

Pursuant to this meeting, efforts were directed towards the preparation of a preproposal document with input from the four member institutions in the consortium.

A series of meetings was held during the spring and early summer of 1990 which culminated in the completion of the preproposal entitled "Long Island Center for X-ray Lithography." That document is attached as the primary product of this contract. It provides the background and outlines a project plan for rapid startup of the Center beginning at the National Synchrotron Light Source, and progressing to a separate facility housing a dedicated compact synchrotron x-ray source, and associated beamlines with microprocessing apparatus for chip technology research and development.

Work is continuing beyond the termination of this contract to secure funding from several sources including the consortium members and New York State for the purpose of preparing a complete design report for the Center. The objective is to use this report to obtain funding for the proposed Center in a phased program that leads to the dedicated facility mentioned above. At this writing, the consortium is awaiting word from the State Department of Economic Development regarding its interest in considering an application for a Regional Economic Development Grant. The idea will be presented to the Long Island Regional Economic Council Executive Committee for a decision in October 1990.

Preliminary Plan

An Eastern Regional Microprocessing Applications Center (To be included with invitations to a CAMP workshop)

Objective

This paper presents a plan for a regional Center to provide the focused, integrated development effort required for U.S. industry to be competitive in the 0.25 micron and smaller mass-produced microchip markets of the future.

Introduction and Background

Japanese industry has mounted a major effort focused on capturing the 65 Mbit 0.25 micron Dram market. The technology that is featured is synchrotron-based x-ray lithography. The program is fully integrated across all necessary technologies. A smaller but also focused and integrated effort is underway in Germany. In the United States, IBM is developing the technology and supporting efforts by equipment manufacturers to supply the synchrotron source, steppers, aligners and other technologies. To remain competitive, it is important that American companies develop plans to produce commercial versions of these tools. Advanced microelectronic technology is the foundation of our most important industries; namely, supercomputers, telecommunications, defense electronics, high definition television and information management and processing.

Starting in 1986, Brookhaven has sponsored several workshops that have identified the need for an integrated facility where American industrial, academic and Federal laboratory collaborators can conduct the research and advanced development necessary to compete in future high-density chip markets. SEMATECH, supported by U.S. industry and government, is investing \$200 million per year in developing the tools and process technology to reach the limits of optical lithography. No equivalent effort is being applied to x-ray lithography, or to other technologies for smaller feature size production. DARPA-funded programs exist for a compact synchrotron and some beam line-related research, but these are widely dispersed geographically and not part of an integrated effort. The DOE is currently seeking industrial partners to design and construct additional x-ray rings, but these plans are still in their infancy.

The critical finding of the fifth BNL x-ray lithography workshop was that the nation needed an integrated central development program as soon as possible. Given the recent emphasis on State support and the paucity of Federal funding, the premise of this paper is that if a focused, integrated U.S. Effort is to commence, the initial funding will have to come from state governments with industry matching funds to draw the necessary Federal support and promote regional economic development. Because the Northeast has a stellar mix of university, industrial and laboratory resources, this paper is direct toward describing a plan whereby these can be mobilized to address this national need.

Operating Philosophy

This Center could commence operations immediately using the research capabilities at Northeastern Universities and beam lines at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory. Industrial, university and laboratory research staff will participate at their own labs and at the NSLS. The organizing principle for the Center will be to maintain a limited staff engaged primarily in coordinating applications oriented research efforts at various institutions and research facilities. The Center will acquire an optimized source as soon as possible. This source will be located in an operating environment that is conducive to full development of the tools and know-how necessary to provide U.S. industry with competitive manufacturing capabilities, not only for chips but also for sources, beam lines, steppers, aligners and other equipment, and mask and including resist technology. Although the initial focus will be upon x-ray lithography the Center will encompass emerging technologies that will be based upon photon assisted fabrication processes.

In order to be effective, the Center will concentrate on providing integrated resources for microprocessing in the VUV and X-ray spectral range. A critical requirement is that clean room environments must be integrated with the exposure sources. These resources will be of general utility to Center members and not readily available at their home institutions. The NSLS and a dedicated synchrotron ring are examples of such resources.

Startup Costs and Ultimate Level of Effort

The ability of startup quickly is the key to success for this concept. Therefore the founding participants should be those in the region who are already familiar with the status and problems associated with the next

generations of microchips. Funding will be sought from State governments and industry in the Northeast. A schedule will be developed initially using State funds and will build to the desired level. State contributions will phase down to maintain a constant continuing support level as commercial funding increases.

A Steering Committee will be established consisting of seven members who meet weekly to complete the following tasks:

- define the form of a nonprofit corporation to develop a technical management plan for establishing offices and a small laboratory near an available light source in the Northeast.
- identify the most significant organizations (industrial, academic and governmental) within the region that would participate in and benefit from the Center, and
- plan for liaison with counterparts in other regions of the country and with Federal government agencies.

Function

The Director of the Center working with its Executive Committee will discharge the necessary functions to promote regional goals of the organization. The primary responsibilities of this group will be to start fund raising and movement towards establishing an information center, recruiting a small technical staff for initial research and technology transfer and planning for a dedicated laboratory to be established in a second year. An important function will be liaison with the existing NSLS User Executive Committee and Association of Users (composed of 125 corporate and other institutions) through its Executive Committee. Effective use of the NSLS will require careful planning to optimize the use of beam line facilities without interfering with existing or planned usage by the present NSLS user community.

In its first year, the major function of the Center will include a review of technical needs and existing resources of the microelectronics industry in the region. This survey will permit an economic and technical analysis to identify promising regional research projects and project teams. The Center will then assist in arranging for funds from State, industrial, Federal, and foundation sources. It will coordinate selected research projects, reinforce information exchange, provide facilities for

meetings, and make an early start towards providing dedicated research space and facilities.

The Center will serve an important function by facilitating technology transfer in a manner that protects intellectual for commercial and national interests.

Technology Transfer

Since the purpose of the Center is to assure an American presence in the high-density memory chip business of the late 1990's and in future photon-assisted fabrication technology, it is imperative that the product of the research and development performed at the Center's integrated facility be accessible to all participating companies. Toward this end every U.S. company will be invited to use the facilities of the Center and to view it as a place where their staffs can learn the technology and receive training in its manufacture, if a tool maker, or its use, if a chip manufacturer. The Center will have to develop the means whereby proprietary claims can be established and cross licensing expedited. Technology transfer will be assisted by encouraging collaborative research and development efforts between industry, universities and laboratories focused on potential applications and testing new products. Experiments may be conducted on the ring although the majority of the effort may take place elsewhere.

The following document is the product of numerous meetings and telephone discussions between members of the Long Island x-ray lithography consortium. It will be used to assist in the solicitation of funds necessary for the preparation of a complete conceptual design report. On the basis of the latter report, the consortium will seek cofunding from Federal, State and industrial sources to begin the creation of the Long Island Center for X-ray Lithography.

July 23, 1990

LONG ISLAND CENTER
FOR
X-RAY LITHOGRAPHY

This is a Preproposal Document.

July 13, 1990

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Executive Summary

This document outlines the format for an X-ray Lithography (XRL) Center on Long Island, New York that can be commissioned in a rapid and orderly fashion to meet the serious challenge from abroad in microchip production for the next generation of microelectronic technologies.

The objective of the proposed center would be to ensure a U.S. leadership role in future microelectronics production by supporting the development of x-ray lithography (XRL) and associated processes and equipment through the creation and operation of an XRL Resource Center.

To accomplish this goal we plan to assemble a consortium of industrial and academic organizations with Brookhaven National Laboratory to be funded jointly by federal and state governments and industry.

The mission of the consortium will be (1) to demonstrate the design, construction and manufacture of self-contained x-ray synchrotron storage rings; (2) to develop an infrastructure with a strong emphasis on both pure and applied research and development to utilize and apply this x-ray technology and (3) to initiate development and manufacturing studies required to produce state-of-the-art microprocessors and DRAMS.

The consortium would begin immediately by adapting existing beamline facilities at the National Synchrotron Light Source with the addition of associated clean rooms and support space. Concurrently, planning would begin for a separate XRL facility based upon one or more dedicated synchrotron x-ray rings.

Background

One highly visible symbol in the current debate over U.S. international competitiveness is the microelectronics industry. For reasons that have been spelled out frequently in the press and government reports, the future status of the domestic microelectronics industry is in doubt. Offshore counterparts have overtaken significant parts of the U.S. industrial microelectronics sector, and are rapidly positioning themselves through vigorous and well-financed research and development programs to completely dominate our domestic microelectronics effort by the end of this decade.

In addressing this challenge one critical issue is deciding which technology to support as the most cost effective for fabricating high-density chips. Competing technologies include deep UV, optical, electron beams, ion beams and x-rays. The lead time for the introduction of a new technology onto microchip production lines has been shortening steadily. A realistic analysis would place this time at 3-5 years owing to improvements in yield and cost considerations on high-volume products such as microprocessors and DRAMS. The shrinking lead time reinforces the compelling rationale for pursuing a strategy with a realistic time line that does not concede the race to the opposition by default.

The national strategy that has evolved is one which initially promotes rapid advances in optical lithography utilizing deep UV sources. It assumes that at an appropriate time x-ray lithography based upon 1x masks and proximity printing will supplant optical technology. The cross over point may be at the 64 Mbit DRAM. Ultimately, reflection and reduction optics for x-ray lithography would be introduced, and could supplement or perhaps replace proximity-printing methods. X-rays are expected to be particularly suitable for high-volume production such as that required for memory chips (DRAMS). IBM has already taken a lead at Brookhaven in demonstrating the advantages of XRL techniques for proximity printing. AT&T (also at Brookhaven) has demonstrated the very high resolution

(500 Å) possible through projection printing. Both of these R&D programs need to be optimized and adapted for the manufacturing industry. This process ultimately will require a dedicated x-ray source rather than the parasitic operations used to date and will only be competitive if supported by a comprehensive, supportive, research and development program.

Although industrial experts are not in unanimous agreement on this scenario, a growing number ultimately will be drawn into the x-ray lithography pathway. To advance development of XRL as a manufacturing technology the microelectronics sector will need support through an integrated facility that can serve as a site for research, development and testing of new ideas. IBM and AT&T have been conducting major lithography efforts at Brookhaven's National Synchrotron Light Source (NSLS). IBM will move to its own XRL facility at East Fishkill, New York in the next year. This allows IBM to take advantage of yield increases demonstrated on pilot line work at Brookhaven. The company supports establishment of a generic XRL Center, and helped to formulate such a recommendation at the Brookhaven XRL Workshop on November 16-17, 1989.

The urgency of this matter cannot be overstated. Evaluation of competing technologies for future generations of chips must be in progress soon. It is important to begin to implement a coordinated XRL effort based upon the sequence outlined above as the most probable course of events. This document suggests the most efficient, cost-effective way to attain that initial goal by building upon the unparalleled infrastructure and experience already in place on Long Island, New York to create an XRL Center.

Justification

A general justification for the creation of a center that houses a prototype x-ray lithography production facility (source, beamlines, stepper-scanner, etc.) can be found in numerous reports of committees and workshops, in journals and media accounts published

over the past five years. For more details the reader can refer to reports¹ by the Defense Science Board Task Force on Semiconductor Dependency (1987), the White House Science Council Panel on Semiconductors (1987), the National Advisory Committee on Semiconductors (1989), the Ad Hoc Study Group on Advanced Lithography (DARPA, Jan. 1990) and the series of five Brookhaven National Laboratory Reports that are the proceedings of workshops convened to assess x-ray lithography. The arguments presented here echo the conclusions expressed in those documents and address the relevant points made therein.

The basic premise underlying this proposal is that the United States cannot afford to permit its competitive edge in the microelectronics field to erode further. The reasons are primarily economic, but are certainly rooted in national security as well. Rapid progress in x-ray lithography for microelectronics device production in other countries threatens to undermine efforts in the U.S. to retain a competitive edge. The prospect of becoming dependent upon foreign suppliers for military electronics components is unsettling to the Administration and to Congress. In the industrial sector, concern is mounting over the declining U.S. market share in this very competitive technology.

¹*Defense Semiconductor Dependency*, Defense Science Board Task Force, February 1987.

DOE National Laboratories and the Semiconductor Industry: Continuing the Joint Planning, Manufacturing Studies Board and National Materials Advisory Board, National Research Council, National Academy Press, Washington, DC, 1987.

Annual Report, Subcommittee on Science and Engineering Computing, Federal Coordinating Council Science, Engineering and Technology, FY 1989.

Findings of the Ad Hoc Study Group on Advanced Lithography, DARPA, January 1990.
Reports of Brookhaven Workshops on X-ray Lithography, BNL 52005, 4-5 March, 1986; BNL 38789, 25-27 August, 1986; BNL 52046, 17-18 November, 1986; BNL 52096, 8 July, 1987; BNL 52230, 16-17 November, 1989.

Location of the proposed Center on Long Island has merit for many specific reasons related to the long and pioneering involvement of its institutions and the local concentration of talent and experience which ensures rapid progress toward practical results.

Technological justification

Since the development of XRL is urgent, the availability of relevant scientific and technological skills and programs is critically important to a rapid startup. Fortunately, immediate steps can be taken to develop missing resources which are crucial in establishing a research center based on an x-ray source of appropriate brightness and operating reliability.

Phase I of an x-ray lithography program can begin immediately at the NSLS with input from Brookhaven, Grumman, Columbia, SUNY/Stony Brook and support by the IBM and AT&T x-ray lithography groups. Staff members from other institutions such as Rensselaer Polytechnic Institute and Cornell University are expected to participate as soon as possible. This program can be transferred to the dedicated Center when construction is completed at a designated site in phase III [see Project Plan (p. 13) for description of Phase III tasks]. The major advantage of this initiative is its ability to begin immediately to address microchip manufacturing issues using existing facilities.

There are many elements in a comprehensive program to develop a new exposure tool, and the capability to develop them at the NSLS is evident among current activities identifiable there. IBM and AT&T have been demonstrating the feasibility of developing beamlines, testing and integrating beamline hardware and integrating exposure systems including optical elements and stepper/scanners. They are confirming that the development of these critical components of x-ray lithography can be started at the NSLS even though the ring was not built primarily for XRL. The use of insertion devices such as the transverse optical klystron (or an undulator), permits concurrent investigations of proximity printing and projection/reduction optics. Collaborations with instrumentation firms such as Karl Suss of America and the Silicon Valley Group (formerly the Perkin-Elmer

Corporation) are advancing U.S. strength in the design of the sophisticated hardware that is required to produce dense microchips. Although not included in the initial conversations, these companies and others within and outside the region will be sought as industrial participants. Similarly, unique academic resources such as Cornell's National Nanofabrication Facility and the Polytechnic University Imaging Science Institute will be approached.

Several aspects of the total technology are being addressed by the consortium of Brookhaven/Grumman/General Dynamics. In particular, the development of commercial x-ray sources is proceeding with DARPA support at the Laboratory. This technology-transfer effort will culminate in the demonstration of a compact x-ray storage ring whose energy and mean electron current are optimized for incorporation as the source in a lithography production facility. The design team that has been assembled will be able to work closely in the future with the x-ray lithography specialists in the Center to advance the accelerator design as necessary to keep pace with technical successes and insights discovered on the experimental beamlines at the Light Source. Questions of electron accelerator energy, mean current, dipole-magnet configurations, ring dimensions and magnet temperature can be discussed regularly by research and development teams in close proximity to Brookhaven and Grumman and others with relevant experience who have joined the program. In addition, the NSLS staff have been involved with the design of almost 90 beamlines and experimental stations, and have developed a major center for the mechanical, electrical and safety engineering of all systems. Retention of the DARPA ring at an appropriate Long Island site for the dedicated facility described in Phase III represents an attractive possibility for accomplishing the complete program described here at significantly reduced cost.

The existence of this strong accelerator and instrumentation physics team is a key ingredient for the early stages of the proposed Center. Integration of the local efforts into a national program that includes other centers in Wisconsin, Stanford, Louisiana, and the Sematech network requires a continuous dialogue concerning x-ray sources and

instrumentation. This dialogue will also address other options such as the UV free electron laser (FEL) and plasma-driven x-ray point sources. The FEL program in Brookhaven will serve as an important link with these technologies.

Scientific and educational justification

The formats that have been adopted for x-ray lithography programs at IBM and in Japan recognize the need for continuous basic and applied research and development in materials science. This work will take place at universities and other laboratories, as well as at the x-ray ring itself. Hence, IBM plans to allocate an appreciable number of beamlines at its new East Fishkill, New York facility for materials-science based R&D. Similarly, testing of new materials for masks can begin at the NSLS and continue at the proposed Long Island Center. Sensitive new x-ray photoresists, multilayer films and reflective masks can also be studied. Radiation resistance of any new materials and ultimately radiation resistance of new devices also can be investigated under appropriate conditions at the NSLS.

The scope of the relevant scientific activities now underway at the NSLS is apparent in the brief descriptions of the research at each of the nearly 90 beamlines contained in the NSLS users' manual. Moreover, the participation of outside institutions, academic, industrial and Federal, permits immediate contact with appropriate and knowledgeable individuals. A good example of this potential can be cited in the requirement for sophisticated metrology in connection with mask development, inspection and repair. Even an ultimate decision to utilize reflection optics and 4x masks will not reduce the importance of metrology to the lithographic processing of materials. At the Light Source a group spearheaded by Stony Brook faculty is on the forefront of x-ray microscopy employing holographic sciences while other Stony Brook faculty are performing photochemistry and photophysics experiments; at the same time, on another beamline researchers from the National Institute of Science and Technology (NIST) have conducted microelectronics-related research in collaboration with AT&T and other institutions. These kinds of

fundamental scientific endeavors that underlie the x-ray lithography technology can be found throughout the NSLS among teams of participating scientists who represent a natural resource for the proposed new Center.

The educational strengths of the Long Island region are well-known. Columbia University and the State University at Stony Brook form the two ends of an education axis that includes Hofstra and Adelphi Universities, Polytechnic University, the New York Institute of Technology, the SUNY College of Technology at Farmingdale and numerous smaller state and private institutions of higher education. Together, they constitute the formidable pool of technical, professional and scientific/engineering talent necessary to the success of a Center. These institutions are interested in developing curricula and technical training programs that will ensure a steady supply of people with the necessary mix of skills for supporting regional technologies. Each has outreach programs to encourage new students to select technical careers recognizing the projected nationwide shortage that will develop during this decade.

Long Island's population is approximately seven million, and inclusion of the educational resources that lie within New York City (besides Columbia University) results in a list of impressive academic and research strength. New York University, City University and Polytechnic University annually produce outstanding graduates in science and engineering. Experience has shown that these young people want to remain in the New York Metropolitan area. An X-ray Lithography Center will attract new industry and thereby serve as a magnet for holding this talent in the region.

Regional and demographic justification

All of the consortium participants have had a long history of involvement in lithography and its associated microscience. Thus, establishment of an XRL facility which emphasizes preproduction advanced technology can be aided by this combination of complementary strengths in order to ensure its rapid success. The Long Island region in this instance is unique. One of its major scientific employers, Brookhaven National

Laboratory, has been involved in aspects of x-ray lithography technology for more than ten years. A major employer, Grumman Aerospace Corp., has worked closely with IBM. Furthermore, Grumman and the General Dynamics Corp. are subcontractors working closely with accelerator designers at Brookhaven to design and fabricate a commercial prototype compact synchrotron for x-ray lithography. They have had many years of experience in accelerator construction including components of the Tokamak at Princeton and linear accelerators and neutral particle beam facilities for SDI applications.

The National Synchrotron Light Source at Brookhaven has been the site of IBM's program for the development of a viable x-ray lithography exposure tool (source, beamline and stepper/scanner). AT&T has independently initiated a program at Brookhaven in x-ray projection optics to define and solve the problems specific to that form of lithographic processing. These two activities and their parent organizations constitute a major regional and state asset which would provide new opportunities for Long Island's established force of small high-technology companies and foster additional development. The Laboratory carries out a broad program in applied science and materials characterization, and has a world-renowned staff of accelerator designers. Its staff is a major source of beamline design, operation and management skills.

The academic and research base that augments this sophisticated infrastructure is also very strong. The State University of New York at Stony Brook has a vigorous Department of Materials Sciences and Engineering, which heads one of the Participating Research Teams at the NSLS, and Stony Brook engineering, chemistry and physics faculty perform research at the NSLS relevant to the lithography process, including mask fabrication, delamination and metallization of microscale objects, and photochemistry. Much of this research falls into the field of surface science, which addresses issues critical to the development of x-ray lithography. An undergraduate materials science program is being planned to complement established graduate offerings. Nearby smaller institutions also graduate highly-qualified technically-oriented students, and the community colleges of

Nassau and Suffolk Counties have played a key role in training support staff for programs at Grumman and Brookhaven. They are important sources of continuing education for upwardly mobile young workers.

In Manhattan, Columbia University is the site of major research laboratories: the Columbia Radiation Laboratory, Center for Telecommunications Research and the Microelectronics Sciences Laboratories. These three captive institutes make up one of the largest electronics programs in the country. The MSL's program in photon-assisted processing is one of the most fundamental in the nation, with a major focus on surface science and photon-assisted processing on surfaces. Columbia has numerous programs with companies and research institutes currently utilizing the Brookhaven Light Source.

The infrastructure and technical interactions between major institutions in the Long Island region and key industrial organizations in the microelectronics field are already in place. The sizable concentration of defense electronics firms in the Long Island area can also act as a resource and stimulus for technology development. An XRL Center would coalesce these forces in a significant manner.

Thus, Long Island is an ideal location for this Center. Its activities and the industrial activity that it will spawn fit the traditional economic profile of the island. Its insular location has ordained that intellectually-based activities leading to high-value added manufacturing dominate Long Island industry. The current and planned cutbacks in defense expenditures will release high-quality technically trained resources. Since the major defense contractor, Grumman, would play a central role in the Center and in producing the manufacturing equipment derived from the Center, many of the personnel needs might be met without individuals changing employers.

This economic portrait is bolstered by the high-quality labor force, the easily accessible educational institutions and the high-technology infrastructure that has been described. Active involvement of the universities in the Center and in the unfolding of these new technology frontiers can assure retraining of the existing labor force, training of

new entrants and participation of scientists, engineers and other professionals at the knowledge frontier.

Experience

Two ideas permeate the preceding discussion: the need for an early start, building on strong, established resources of outstanding quality and the importance of creating a user-friendly operation for the industrial development of XRL. The collection of founding institutions: Brookhaven, Grumman, Columbia and Stony Brook is ideal for meeting these two essential criteria.

The NSLS was created as a user-friendly facility, indeed would not have been approved for funding otherwise, and has developed a detailed administrative policy for simultaneously accommodating a continuous flow of researchers from scores of research and industrial institutions. Its successful operations have become a prototype for future large facilities such as the Advanced Photon Source now under construction at Argonne National Laboratory and the Advanced Light Source at Berkeley. The policy for gaining access to beamlines fosters the possibility of an early start for Center-related activities. Submission and approval of a proposal for research on a specific beamline results in allocation of beam time under a policy that makes available up to twenty-five percent of such time on all non-proprietary beam lines.

The experience gained at Brookhaven in dealing with almost 2,000 academic, research and industrial users constitutes an invaluable resource for planning an X-ray Center intended to function on a similar basis. Ultimately, variations of that mode which will enable the Center to become self-supporting will have to be developed. But they can evolve from a system that gets off to a smooth and fast start by adopting the NSLS policies and modifying them later.

Project Plan

Plan of Accomplishment.

The plan for a Center for X-ray Lithography can be achieved in three phases:

Phase I

- Program Development and Conceptual Design plans that will lead first to funding for early research and for the design of the storage ring(s), injector, beamlines and building. Funding in later years will support procurement and construction of these program elements. Simultaneously, Center operations in this Phase would begin at member institutions and at selected beamlines at the NSLS. A clean room environment will be required at one of the beamlines.

Phase II

- Establish working structure and management plan of the Center.
- Integrate goals and schedules with national agenda.
- Begin R&D at the NSLS on existing beamlines.
- Develop new beamlines and supporting clean rooms at the NSLS for materials and components research.
- Detail design or plan of acquisition of
 - X-ray source(s).
 - Beamlines and exposure stations.
 - Building and support facilities.

Phase III

- Procurement or acquisition of x-ray storage ring(s).
- Construction of building and support facilities.
- Procurement of beamlines and exposure stations.

Facility description.

The facilities we propose will be based upon the recommendations of the 3rd BNL XRL Workshop .

The Center for X-ray Lithography could, as was suggested in the Report of the Third Workshop contain the following five elements:

- Room temperature magnet storage ring ("warm" ring).
- Superconducting magnet storage ring ("cold" ring).

- Injection system.
- Beamlines.
- Building.

To which we now add new elements:

- Research and development.
- Application to industrial needs.
- Exposure hardware.

Costs and schedules will be dependent upon whether an existing source will be utilized (i.e., the DARPA superconducting ring under development at BNL), an existing warm or cold ring design is used, or a next generation storage ring is needed.

The Third Workshop and a follow-on study sponsored by DARPA called for a building of about 46,000 ft² to house a room temperature storage ring, experimental hall, and about 6000 ft² of clean rooms. In addition, there was 8000 ft² for the superconducting magnet x-ray source. Adjacent to the Storage Ring and Experimental Hall Building will be a two-story Office and Laboratory Building of about 26,000 ft² for the experimenters and operations staff.

The Third Workshop envisioned a 37-meter circumference normal-temperature magnet storage ring with an energy of 1080 MeV and critical wavelength of 10 Angstroms. The "cold" ring had an energy of 728 MeV and a circumference of 10.2 meters. A common full-energy injector was a 75 meter long 1 GeV linac which was connected to the storage ring by a long beam transport system.

For the purpose of this study, we will assume the same 37-meter circumference "warm" ring with 16 ports, then substitute more recent data for the superconducting ring, which is $E=696$ MeV, circumference = 8.5 m and $\lambda_c=10$. The injection system will also be scaled down to a 200-MeV linac and much shorter beam transport.

Schedule.

A tentative schedule suggests that if a high level of effort is made and funding is available for design in October 1990 and for procurement beginning October, 1991, the Center could be completed by Spring 1995. Needless to say, if a storage ring and injector such as the ones now being designed and procured at the NSLS under DARPA sponsorship were made available to the proposed Center, completion could occur a year earlier if the facility design and construction is accelerated. During all of this period important research and development could be going on at existing NSLS beamlines and elsewhere. It is possible to accelerate the schedule by beginning design of the building and accelerator as early as FY 1991 if funding permits.

Costs.

Even a rough estimate of costs is difficult to make before a more comprehensive study is completed. For the purpose of this document a summary of costs is as follows:

	<u>\$Million</u>
• Room temperature storage ring	20.0
• Superconducting magnet storage ring	22.0
• Injector system	5.0
• Beamlines (assume 4 for this program, Steppers not included)	4.2
• Building complex with clean rooms (exclusive of cost of land)	23.0
• Phase I (Program Development)	0.6
• R&D at NSLS and elsewhere (assume no clean room) Assume \$1million first year and \$2 million for 3 years thereafter	<u>7.0</u>
	\$81.8

Notes

1. All components include design and contingency costs.
2. Costs are shown in 1990 dollars and are not escalated to dates of procurement.
3. Addition of clean room at NSLS would cost ~\$1M.

There is great flexibility in the funding approach. While the Center for X-ray Lithography may be designed to evaluate current (and future) storage rings, a decision may be made to start with one rather than two storage rings. This would reduce the total estimated cost to about \$60 million. If, as previously noted, the DARPA compact ring and its injector were sited at the proposed Center, the estimate would be very significantly reduced to less than \$40 million. A new building to accommodate only one storage ring, or utilization of an existing building would reduce the Center's cost further.

The cost in the first year (FY 1991) for Phase I and the start of Phase II R&D is relatively small, only \$1.6 million. Even the second year's estimated cost is low since it involves a modest amount of R&D (\$2 million) plus some increment for design of the source (if required), the beamlines and the building. The impact of significant expenditures will not occur until FY 1993 and FY 1994 when procurement and construction will begin.

A much more comprehensive schedule and cost estimate will be developed as part of Phase I activities.

Organizational matters.

Operating philosophy

This Center could commence operations immediately using the research capabilities of participating corporations and universities, and beamlines at the NSLS. Industrial, university and laboratory research staffs will participate at their own labs and at the NSLS. The organizing principle for the Center will be to maintain a limited staff engaged primarily in coordinating applications-oriented research efforts at various institutions and research facilities. The Center will acquire an optimized source as soon as reasonably possible. This source will be located in an operating environment that is conducive to full development of the tools and know-how necessary to provide U.S. industry with competitive manufacturing capabilities, not only for chips but also for sources, beamlines, steppers, aligners and other equipment, and including mask and resist technology. Although the

focus will be upon x-ray lithography the Center will be prepared to encompass emerging technologies that will be based upon photon-assisted fabrication processes.

In order to be effective, the Center will concentrate on providing integrated resources for microprocessing in the VUV and X-ray spectral range. A critical requirement is that clean-room environments must be integrated with the exposure sources. These resources will be of general utility to Center members and not readily available at their home institutions. The NSLS and a dedicated synchrotron ring are examples of such resources.

Startup and interim management

The ability to startup quickly is the key to success for this concept. Therefore the founding participants should be those in the region who are already familiar with the status and problems associated with the next generations of microchips. Funding will be sought from Federal and State governments and industry. A schedule will be developed initially that anticipates using government funding and builds to the necessary level. As commercial funding increases, government contributions would decrease so as to maintain a constant level of continuing support.

A Steering Committee will be established consisting of seven members who meet weekly to complete the following tasks:

- Define the form of a nonprofit corporation to develop a technical management plan for establishing offices and a small laboratory.
- Identify the most significant organizations (industrial, academic and governmental) within the region that would participate in and benefit from the Center, and
- Plan for liaison with counterparts in other regions of the country and with Federal government agencies.
- Invite other organizations to participate in the Center.

Management

The Director of the Center working with its Executive Committee will discharge the necessary functions to promote regional goals of the organization. The primary

responsibilities of this group will be to start fund raising and movement towards establishing an information center, recruiting a small technical staff for initial research and technology transfer and planning for a dedicated laboratory to be established in the second year. An important function will be liaison with the existing NSLS User Executive Committee and Association of Users (composed of 125 corporate and other institutions) through its Executive Committee. Effective use of the NSLS will require careful planning to optimize the use of beamline facilities without interfering with existing or planned usage by the present NSLS user community.

In its first year, the major function of the Center will include a review of technical needs and existing resources of the microelectronics industry. This survey will permit a subsequent economic and technical analysis to identify promising research projects and project teams. The Center will then assist in arranging for funds from State, industrial, Federal, and foundation sources. It will coordinate selected research projects, reinforce information exchange, provide facilities for meetings, and make an early start towards providing dedicated research space and facilities.

The Center will serve an important function by facilitating technology transfer in a manner that protects intellectual property for commercial and national interests.

Technology transfer

Since the purpose of the Center is to assure an American presence in the high-density memory chip business of the late 1990's and in future photon-assisted fabrication technology, it is imperative that the product of the research and development performed at the Center's integrated facility be accessible to all participating companies. Toward this end every U.S. company will be invited to use the facilities of the Center and to view it as a place where their staffs can learn the technology and receive training in its manufacture, if a tool maker, or its use, if a chip manufacturer. The Center will have to develop the means whereby proprietary claims can be established and cross licensing expedited. Technology transfer will be assisted by encouraging collaborative research and development efforts

between industry, universities and laboratories focused on potential applications and testing new products. Experiments will be conducted on the ring although the majority of the effort may take place elsewhere in a given case.

Concluding remarks

Adoption of a long term national strategy to secure U.S. leadership in microelectronics requires near-term action on the establishment of an X-ray Lithography Center to support precompetitive advanced development by industrial users, as well as supportive research and development by university and Federal laboratory personnel. This document describes a means of accomplishing that end utilizing existing expertise and facilities while developing future resources.

A consortium of recognized institutions in the Long Island region with a decade of experience in lithography science and technology can begin almost at once to implement the plan. The plan ensures continued international competitiveness on the leading edge of x-ray lithography. It provides a key resource to an industry that is already moving in the direction of a unified approach to the design and production of future high-density chips, which has significant implications for regional economic diversification and development.

A modest input of first-year funding from State, Federal and industrial sources will enable the consortium to take the first critical steps in a multiyear plan to create a Long Island X-ray Lithography Center.

NEW YORK STATE SCIENCE AND TECHNOLOGY FOUNDATION
FINANCIAL STATUS REPORT

Institution: Brookhaven National Laboratory Total Award: \$60,000

Grant Number: 88029 (ENL A/C 87508)

Grant Period: 06/21/89 to 09/30/90

Completed by: J. M. Sperry

Foundation Funds:	Cumulative	Budgeted
Salaries	\$38,476.64	\$25,674.00
Fringe Benefits	\$10,965.86	7,317.00
Indirect Costs	7,416.38	4,949.00
Supplies & Materials	619.11	1,060.00
Equipment Costs		
Travel	2,506.34	12,000.00
Computer Services		
Publication Costs		
Other (identify)		
Workshop		5,000.00
Other		4,000.00
Total Amount:	\$59,998.33	\$60,000.00

END

**DATE
FILMED**

3 / 23 / 92