EVOLUTION OF THE MICROFABRICATION FACILITY AT BERKELEY

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Memorandum No. UCB/ERL M89/109

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Katalin Voros, Microlab Manager
Ping K. Ko, Faculty-in-Charge

ABSTRACT

The Berkeley Microfabrication Facility has been in operation since 1962. It is a shared facility that supports a wide variety of experimental research in microelectronics and other fields. Currently, 46 faculty investigators and 153 graduate students use the facility. The Microlab is used principally to fabricate devices and structures that cannot be obtained through commercial sources. Principal operators are graduate students. A professional and technical staff of 13 full-time equivalents supports the processes, equipment and facility.

Policies and operating procedures have developed over the years to provide economical support for diverse technical procedures. This report describes our important policies and procedures, including those relating to training, safety, maintenance, budgeting, technology upgrades, and sharing of sophisticated research equipment. Faculty and students consider the Microlab to be an excellent and indispensable tool in their research.

September 22, 1989

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I. Introduction

The Microlab frequently receives visitors from representatives of U.S. and foreign universities who are planning or building new microfabrication facilities. While most of them are aware of the high cost of building a laboratory, few express much concern about finding the money to operate and maintain it once it has been built. After running our lab for over 25 years, we feel that the issue of operating costs is far more important than most people think. For us, the battle to balance the operating budget has been long and hard. At present, we are still far from winning it, although we have had some successes after various cost control and revenue expansion measures were put in place. While the financial support structure, scale of operation, and missions of other labs may differ from ours, we believe that many of the problems we have been struggling with are fundamental, and that every lab's management will eventually have to deal with them. In this report, we shall review our experiences in physical development, operation and financing of our lab. We hope that those embarking upon similar endeavors will find them useful.

Before going into details, however, we would like to say that the type and scale of a university laboratory should be in line with the existing and planned research activities and with the realistic support likely to come from them. Grants obtained for lab construction and startup are quickly expended, leaving the organization to its own resources. Without a strong supporting base, maintaining a working IC lab is infeasible.

Throughout this paper we will use the terminology "working" lab and "capability to build chips" as suggested by J.D. Plummer in his report, *Building Chips in a University Environment - The Stanford BICMOS Project, October 1988*. Plummer defines "the capability to build chips as being able to fabricate an IC containing several thousand transistors in a reasonably advanced technology such as 2 micron CMOS"; and a "working" lab as one "in which the equipment is operational most of the time; one in which the equipment is characterized; one in which processes (oxidations, implants, CVD, etc.) are run often enough that they are understood and reproducible; and one in which technical assistance is available to students to run complex pieces of equipment (implanters, for example)." These terms apply to the Berkeley Microlab.

II. Development of the Berkeley Microfabrication Facility

History

Microelectronics research and instruction began at Berkeley soon after the invention of the chip. A 1200-square-foot laboratory was constructed and the first working circuits on 3/4-inch-diameter silicon wafers emerged in 1962. A major goal of this effort was to demonstrate the feasibility of IC research in a university environment.

During the 60's laboratory activities expanded to include complete bipolar processing along with the development of novel IC design techniques and the widely accepted SPICE circuit analysis program. In the 70's, analog MOS research led the way, and successful ideas developed at Berkeley became widely used in industry. The second half of the 70's also brought about the emergence of MOS device and technology research, and the development of process CAD tools, such as SAMPLE. Research in circuit design continued to be a strong program, in both bipolar and in MOS technologies, resulting in new concepts such as switched capacitor filters and A/D, D/A converter circuits.

Most of the IC's designed and published up to 1983 by Berkeley researchers were fabricated in-house, in what we now call the "old lab". By the end of the 70's however, it was obvious that to keep up with the pace of developments in the industry and to enable fabrication of more complex, higher density chips, a new, modern facility was needed.

Specific planning for renovation and expansion began in 1979. A state appropriation of $2.4 million was obtained and defended against a series of statewide budget cutbacks and freezes. Additional funding for research equipment was obtained from industry ($1.1 million), federal agencies ($570,000), and the Regents of the University of California ($500,000), for a total amount of $4.57 million. Construction costs, to build a new lab inside an existing building, were $1.1 million. The rest of the funds, $3.47 million were spent on new equipment.

During construction, which started in 1981, work in the old lab proceeded more-or-less undisturbed until the new lab opened in the Fall of 1983. At that time, the two sections were joined. Access to the old lab was provided through a door from the main hallway of the new lab. At present, the total area of the Microlab is approximately 10,000 square feet; about half that area is maintained under Class-100 clean room conditions.

Looking back after four years of successful operation (1985-89), we have to conclude that the original plans were well conceived. Most of the decisions which were made because of space and financial constraints were good compromises. Even major concessions which carried the potential of adverse impact on the lab did not prove detrimental.

Some examples of successful decisions:

- One decision, which turned out to be extremely judicious, was equipping the mask shop with an optical pattern generator. Readily available masks made by students, or by staff as a service, provide tremendous flexibility to any project. The GCA 3600 pattern generator has been the most heavily used equipment in the past 3 years.
- A laboratory design comprised of some small separated rooms, general areas, and a more-or-less isolated VLSI area at one end, turned out to be advantageous. This advantage manifested itself to a great extent when research emphasis changed from the planned silicon chip fabrication to more heterogeneous, all-encompassing activity. The layout of the lab made it possible to dedicate rooms to special work and to minimize interference between processes.
- Another decision, to fully computerize the new lab, — to render it "paperless" as the initiating researchers called it, — had unforeseen ramifications in managing the lab. Besides their research value, the programs resulting from the CIM project are extremely useful tools in both facility and fiscal control. This concept will be discussed later in more detail.

Some examples of unsuccessful decisions:

- Lack of funds necessitated keeping the 10 year old ion implanter and rebuilding it in-house to accommodate 4" wafers. This machine became a maintenance nightmare and was never able to deliver implants with the accuracy we need.
- Some equipment we bought was of unproven new design; thus, we had to invest a tremendous amount of time characterizing, operating and maintaining these machines. Start up time was long and no revenue was coming in because users were not satisfied with the results produced.
- We have embarked on too many in-house equipment rebuilding/upgrading projects, with the intention of cost savings. Most of these turned out to be costly both in time and money.
- The hardest problem to deal with, however, was the limited service and storage area provided. With 108 operative systems to maintain — there is not one piece of equipment in the lab which is not

being used — logistics quickly become a major concern. The lack of a *dirty* repair shop, where pumps and machines can be repaired and rebuilt, places an undue burden on the maintenance staff. This problem is currently being remedied by the assignment of an additional room adjacent to the lab.

The original design team did an excellent job given the constraints of space, money and time. This emphasizes the fact that it is very important to have people with strong technical competence and extensive hands-on experience involved from the very beginning in the design and construction process. All in all, the facility serves its researchers well, although the current needs are quite different from those for which the laboratory was planned.

Changing Policy

The new facility was planned with chip fabrication as the major activity in mind. It was to provide:

1. a working laboratory for students who wished to build their own circuits;
2. a foundry service for the systems group.

In return, we expected the circuits and systems people to be the main financial supporters of the lab. This was, of course, before the inception of MOSIS — the highly successful DARPA/NSF program, to provide university researchers with chip foundry services for industry-standard MOS LSI processes at little or no cost.

It took us two years (1983-85) to render the lab fully operational; to have a 2 μm CMOS process in place supported by fully trained personnel. Unfortunately, by the Fall of 1985, when we were ready, IC business had all but vanished from the lab due to the success of the MOSIS service. At that point we had an accumulated debt to the University of about $400K. The deficit resulted from construction overruns and operating expenses during construction and start-up. While there was no revenue, staff had to be retained because they were essential to the expansion, renovation and start-up. With this burden on the lab, we were forced to do some careful planning. The primary goals of the lab, support of research and teaching, did not change, but it was clear that adjustments were needed if the users were to fully support the lab.

With the IC and systems business gone, we looked to our other groups for increased activity. Fortunately, we always had a very diverse program, from which device and technology development emerged in 1986 and continue to date as main groups supporting the lab. In addition, after some quiet years doing preparatory work, the sensors people burst upon the scene in full force in 1987. Sensors research involves both standard MOS and esoteric processes, the latter often detrimental to the former. While maintaining our standard process, we rendered some procedural changes to accomodate the non-standard needs. We had to give up some of our "MOS mentality" and protectionism. It is a balancing act every step of the way, but it is worth the effort. This approach paid off handsomely. With the establishment of the Berkeley Sensor & Actuator Center, an NSF/Industry/University Cooperative Research Center, in the Fall of 1986, sensors research has become a major source of support.

From early on, the Berkeley Microlab had the tradition of encouraging researchers to join from all other areas of microelectronics as new fields emerged, such as compound and low temperature semiconductors. Thus, non-silicon people were not compelled to establish their own separate labs; instead, they helped to maintain one common facility. By necessity, some equipment was always reserved for dedicated tasks, but other equipment, such as photolithography tools and analytical instruments, were shared. This tradition, carried over to the new lab, has helped us bridge low income times during construction and ramping up operations. Non-silicon researchers continue to be strong lab supporters.

Finally, the lab has always had a group of members from other departments, such as Physics, Materials Science, Chemistry and Chemical Engineering. These users are involved in applying microfabrication techniques to build structures to examine phenomena in their field. We looked at extending this user base by advising them of IC technology, by making minor adjustments to accommodate them, and by extending BMA subsidies. These efforts resulted in increasing the number of non-EE members to 25-30% of the total. As the activity of these people is usually low and/or intermittent, income received from them constitutes only about 10-15% of the total. (See Figures 1 and 2.) They are also more problematic, having no technical support from their own research group. We think, however, that their presence is beneficial and plays an important role in teaching students to embrace a cooperative spirit.

Currently the Microlab has 153 active users. The numbers vary monthly as senior students graduate and new ones join. The total number has been slowly increasing during the past three years and along with it the utilization of and traffic in the lab. We estimate that at around 200 users we will reach capacity, although this will depend greatly on the rate at which each research group grows and the particular demands placed on equipment.

Representative research publications, based on work done in the Microlab, are listed in Table 6.

Some Guidelines

In the previous discussion we described our efforts to halt the down-spiraling financial situation of the lab by finding *modus vivendi* with a changed user base. Slowly, a set of guidelines emerged, which has helped us achieve our goal of providing students with a working lab, and keeps the lab on course with a balanced budget.

Our guidelines are as follows:

1. The lab maintains, with staff, a baseline 2 μm CMOS process to calibrate and exercise equipment and provides standard process modules and foundry service for device and IC people.

2. The philosophy of the lab management is to accommodate the needs of all users, as far as possible without detriment to the work of others. This especially applies to sensors research, which involves both standard MOS and esoteric processes.

3. The lab continues to provide strong support for compound semiconductor research, by maintaining dedicated equipment and addressing special needs.

4. The lab maintains a dedicated room and equipment for superconductor research. Staff cooperate with their research engineer to provide optimum support.

5. The lab maintains a dedicated room and equipment for deep UV photolithography research. Staff cooperates with their research engineers to provide optimum support.

6. Management strongly encourages and helps interested researchers from other departments and from other UC campuses to use our facility.

7. In general, the facility is used to carry out non-standard processes, which are not available commercially.

Implementation of Fiscal Control

In addition to establishing philosophical guidelines for lab operations, we also implemented very strict budgetary control procedures. These involved the following:

1. Yearly budget itemized in detail;
2. Monthly monitoring of expenditures;
3. Manager signing off all non-standard expenditures of greater than $100.00;
4. Careful review of standard and large expenditures;
5. Periodic review of staff allocation;
6. Full computerization of charging procedures;
7. Establishing an efficient structure for revenue collection;
8. Establishing an independent recharge account number for the Microlab.

The lab came under new management in December 1986 and by June 1987, the end of FY 1986/87, we broke even. This requires some explanation.

When the new lab opened for general use, a new recharge structure was initiated, based on estimated expenses and income. Recharge rates were much higher than those in the old lab. Even at the new rates, income fell far short of expenses. Membership was below old levels and many expenditures associated with startup had to be absorbed. This was not unexpected and plans were made early to partially finance the lab from donations during this critical period. The Berkeley Microelectronics Affiliates (BMA) was established in 1984 to provide ongoing support for research and instruction in microelectronics and CAD/CAM. Each BMA company pledged an annual cash grant for a period of five years. The Microlab received from these gifts an annual support which has been gradually reduced as lab income increased. Thus, when we say that in FY 86/87 we broke even, the budget still included a $194K BMA grant, which did not come from users (see Figure 3).

In 1987, the Campus Recharge Committee required that we start paying back some of our debt to the University. In compliance, the last two budgets included a proposed $50K debt recovery, which we met; but again, only with BMA support. At this rate, it will take 8 years to pay back our obligations, if we do not incur new ones. The University does not charge interest on such arrears.

By 1987, income showed a slow but steady increase and we knew who our main supporters were. We restructured our accounting system: instead of the lab receiving a fixed sum from BMA, enabling us to charge lower rates to all users across the board, each PI received an individual grant toward his share of lab expenses. The amount was calculated such that heavy users were subsidized at a higher percentage than light users. Over the last two years, as BMA contribution was slowly reduced, the subsidies to PI's were also reduced and they paid for an increasingly larger portion of lab expenses. This procedure helped PI's to adjust gradually to higher rates.

At the the end of FY 88/89, five years of BMA commitments expired. Subsidies to PI's were discontinued on July 1, 1989. Now comes the real test: can the users fully support the Microlab? The word *fully* is applied loosely here; there are expenditures for which the Microlab does not have to pay.

- The University provides, from research contracts' overhead, *in kind* support in the form of electricity, air conditioning, compressed air, industrial water, recirculating cooling water; building maintenance (outside walls of the lab) and custodial service (floor cleaning inside the lab); and removal of hazardous waste. This list is complete.

- The Department of Electrical Engineering and Computer Sciences pays the salaries of 1.75 FTE's. (Total number of Microlab FTE's is 13.) This is in lieu of the service Microlab staff provides to maintain two undergraduate teaching labs (EECS 143, Processing and Design of Integrated Circuits, in room 218 Cory; and EECS 135, Microwave, Optics and Plasma Laboratory, 391 Cory) both of which are small independent facilities, located on the second and third floors of Cory Hall. (The Microlab is on the fourth floor.) In addition, we do not charge for graduate classes held in the Microlab.

- The Electronics Research Laboratory pays the salary of one Microlab FTE from ERL overhead, as contribution from all member PI's. (Total ERL membership is 75 PI's.)

- The salary of one Microlab FTE is paid by SRC support. (26 PI's are involved in SRC projects.)

- Computer system hardware and software support is provided by the CIM research project.

After everything is tallied, of the 46 PI's who had students in the lab in FY 88/89, one third paid anywhere between \$13K and \$75K, one third between \$1K and \$8K and the last third below \$1K.
(See Table 1.) Total amounts do not include extra supplies, which were bought by students through the Microlab.

Current Budget

The Financial Summary for Fiscal Year 88/89 (July 1, 1988 - June 30, 1989) is shown in Table 2. Supplies and expenses, shown in Table 3, were within 1% of target; salaries and benefits within 3%. Income increased by 17.5% over that of last year. The additional income was due partially to a rate increase in January 1989 in staff service charges and partially to increased lab use, resulting in the desired debt recovery. Figure 4 shows the breakdown of lab expenditures in FY 88/89.

Charges to each researcher using the lab are grouped in five categories. These are:

1. **Access fee** is a fixed sum, charged monthly, as long as an account is active, regardless of lab use. Each user has an individual account and PI's pay an access fee for each account, i.e., for each student, even if the student was not in the lab during the month. This is shown in the Access column of the monthly statement that PI's and their grant administrators receive. (A sample page from a monthly statement is shown in Table 4.)

   An account may be suspended if it is to be reactivated within 6 months. This is important for those students, mostly outside of our department, who, after fabricating a device, need a longer time to test and characterize it. If they stay away for a longer period, they will have to attend the lab orientation seminar and take the safety test again.

2. **Lab use** fees are charged at an hourly rate, computed by the minute from login to logout, for the time users spend in the lab. (The maximum lab fee charged to any student is $1000/month.) This fee covers access to Class-100 clean rooms, and to all processing and analytical equipment except those listed in section 4 below. They receive disposable clean room attire, safety equipment, chemicals, and gases used in semiconductor processing. The lab fee does not cover wafers and photolithography masks.

3. **Staff service** fees are charged at an hourly rate, computed by the minute, for special services provided directly to a student or a project. This service may include certain standard process steps, such as thin-film deposition or mask-making. The scanning electron microscope is operated by staff only; thus, staff service fee is charged for the time spent on a job. There is no charge for consultation time spent discussing projects or providing information.

4. **Special equipment** use fees are charged at an hourly rate, computed by the minute, for using maintenance-intensive equipment in the lab. (The maximum equipment fee charged to any student is $1000/month.) These are the Tylan automated furnaces (11 atmospheric and 5 LPCVD tubes), three plasma etchers (lam1, lam2, ptherm), the Cwickscan scanning electron microscope, GCA 10X

wafer stepper, and the GCA optical pattern generator. With the exception of the wafer stepper and pattern generator, these machines use specialty gases, the cost of which is included in the fee.

5. The Microlab provides a service to its users by handling special orders. If students need special materials, chemicals or gases for their work, they can order it through the lab office and have the cost, without extra charge, applied to their account. These charges, along with those for items obtained from lab inventory, such as silicon wafers and masks, are listed in the **Supplies** column for each account.

Current recharge rates are as follows:

Access Fee	$73.86/month	
Lab Use	$21.90/hour	$0.37/minute
Staff Service	$53.77/hour	$0.89/minute
Special Equipment	$21.60/hour	$0.36/minute

The new budget is based on these rates. We are counting on increased income to offset salary and S&E increases and a $50K debt recovery. If by the end of this calendar year, it does not look like these plans can be realized, we shall have to raise rates.

New Equipment

Under current policies for the Microlab as a recharge unit, new equipment purchases are not included in the budget. Some funds for replacing/upgrading equipment come from BMA allotments, which were, for the last three fiscal years, as follows:

1986/87	87/88	88/89
$117.3K	$74K	$48K

On occasion, professors buy equipment related to their own research. Even though the unwritten rule has been that equipment maintained by staff is available for everyone, this may not be possible because of cross-contamination caused by different processes. To supplement our own resources, we actively solicit equipment donations from companies. We have to be careful, however, of what we accept, to avoid the trap of collecting irrelevant machinery which only takes up space.

III. Current Operations

Maintaining a working university laboratory with capability to build chips is a major effort and commitment on the part of the faculty. The only way we can manage is by taking the following steps:

- pooling all efforts in a common facility;
- keeping expenses under control;
- having a dedicated, professional staff to maintain equipment and processes;
- efficient equipment utilization;
- computerization;
- providing student training and support;
- keeping safety issues in the forefront.

We have dealt with the first two aspects; discussion of the rest follows.

Staff

At present, the Microlab has 13 FTE positions, filled by 15 people, who are directly involved in maintaining operations. This is the absolute minimum number necessary to keep equipment and processes running without unreasonably long down times. Just as there is a critical mass in equipment and utilities necessary to build chips, there is a critical mass in staffing necessary to maintain a working lab. We believe that we are at the lower limit, with nothing to spare.

Figure 5 shows staff allocation and payroll titles, which are indicative of the staff's technical level. Our hands-on supervisors are actually doing a good part of the work for which their group is responsible. In addition, they prioritize jobs, help where necessary, substitute when someone is out, conduct performance evaluations and take care of their subordinates' personal problems. Part-time undergraduate students, one under each supervisor, help out in operating/repairing machinery, stocking supplies inside the lab, maintaining cleanliness, attending to computer problems; and in general, lend a hand wherever they can. After some time-wasting experiences, we established the policy to hire only engineering or natural science majors.

The lab manager is under the administrative supervision of the EECS Department Engineer, who coordinates the work of all technical staff in the building and whose office is the connecting link to Campus Planning and Facilities Management. The Faculty-in-Charge, a professor assigned by the Director of ERL, is the technical advisor to the lab management. (He also evaluates the manager's performance.) Together they develop short-term and long-term goals and policies affecting facilities and process development. He has an active role in overseeing the budget, in purchasing new equipment, and acts as liaison between the PI's and the lab.

1. **Maintenance Staff**

Under the Maintenance Supervisor we have a highly competent technician staff who maintain a wide variety of equipment, from simple bake ovens to sophisticated exposure tools and vacuum systems. The equipment list contains 108 machines with mechanical and/or electronic subassemblies and controls, and a total of 82 vacuum pumps (a mixture of both low and high vacuum pumps).

We found that the job classification best suited to the lab's needs is the Development Technician series (in UCB's technical staff structure), which requires a wide range of skills encompassing mechanical/electrical/electronic repair and design capability. With two other more specialized technicians, a Principal Electronics Technician who takes care of complex electronics subassemblies, and a Principal Laboratory Mechanician, who services and rebuilds all the vacuum pumps, we have sufficient maintenance coverage and rarely need to call outside services. From the beginning, this was our goal and we have come as close to it as possible with available resources.

The Microlab maintains its own utilities, which include deionized water, clean air, N_2, O_2, and specialty gases. To provide uninterrupted service, the maintenance staff must also keep constant vigilance over services supplied by the Campus, such as electricity, industrial water, recirculating cooling water, compressed air, and air conditioning. Problems with these have to be reported to Planning and Facilities Management through the Office of the Department Engineer, and repairs must be followed up with them, to avoid disasters in the lab. The computer program BLIMP, as part of our in-house CIM package, provides help in utilities monitoring and TECHJOB with assignments and prioritizing of jobs.

2. **Administrative Staff**

The Microlab is an independent recharge unit within ERL and as such, we take care of all of our purchasing, inventory and accounting. Our Administrative Supervisor, with the help of a half-time purchasing assistant, does an excellent job of overseeing over 160 recharge accounts; managing accounting; purchasing all materiel, including chemicals and specialty gases; maintaining inventory of supplies; and taking care of the innumerable details involved in servicing a unit of 20 employees. This is possible only with complete computerization of administrative tasks. An example: When entering the lab, students must log in on Argon, the lab computer, prior to use of any equipment. From that time on, lab use charges are compiled by the minute (including special machine charges, if any) and summarized in a monthly statement (itemized by student, PI, charge number, etc.) All income and expenses are entered in BEARS, the University's accounting program, then reconciled against the UCB general ledger. The purchasing assistant also acts as an office receptionist, and fills students' requests for materiel from inventory or through special orders.

3. Process Staff

One of the main components of successful operation of the Microlab is the services provided by the process Staff Research Associates under our Process Supervisor. This job classification series requires graduation from college (B.S.) with a major in an applicable science plus some years of experience, depending on the level within the series, in the kind of work to be performed; or an equivalent combination of education and experience.

Process Staff carry out so-called staff projects, which can be:

- complete integrated circuit processes;
- collaboration with students on joint projects;
- providing continuity of information for the ever-changing user base.

They also carry out operational maintenance. This includes:

- characterization of equipment after repair;
- calibration of analytical instruments;
- maintaining of user manuals;
- changing chemicals in sinks;
- changing lamps in exposure tools;
- operating restricted equipment, such as the SEM.

The process staff, along with the supervisors,

- give lab orientation seminars;
- are active in public relations;
- take care of visitors;
- give limited lab tours;
- conduct informational presentations.

An effective process staff is the key to future developments.

New process development activity decreased greatly when staff organization was restructured and the process engineer became the lab's manager. To ease the financial burden on the lab, the process engineering position was not filled and new process development effectively halted. The process staff's activity was redirected to process maintenance and service to students, coordinated by the process supervisor.

4. Associated Research Staff

Under this heading we are grouping those researchers who, for administrative reasons, are considered Microlab staff, yet are under the direct supervision of PI's and are paid by them. This arrangement was established according to the ERL practice that all staff people should report to staff supervisors and not to professors. This is to avoid an additional administrative burden on PI's and at the same time, to protect employees' interests, such as delivering timely performance evaluations, (done jointly by the PI and the Microlab manager), and relaying of information concerning UC staff policy/benefits changes. Also, the questions of research space and equipment repair priorities can be resolved more easily among staff.

The Development Engineering series defines a professional employee with a B.S. or M.S. degree in engineering and some years of experience, depending on the level within the series, including responsible design work; or an equivalent combination of education and experience. There are no Ph.D.'s on the staff of the Microlab.

Our associated researchers are not independent PI's and are not involved in obtaining grants on their own; they are working with their groups to enhance the progress of specific projects. They have no maintenance responsibility in the lab; their dedicated equipment is maintained by the maintenance staff. On the other hand, PI's pay lab fees for associated researchers, same as for any student user. (They are exempt from paying when the engineers are repairing/rebuilding their own machines.) Our four main research groups employ associated researchers. They are listed in Figure 5.

Processing Equipment

Table 5 contains the list of equipment available in the Microlab. These can be grouped into three categories:

1. New (in 1983) equipment for mask making and 4" silicon processing; (60 pieces of equipment fall in this group)
2. Old rebuilt/retrofitted/remodeled equipment to accommodate 4" wafers; (11)
3. Dedicated equipment, both old and new, for non-silicon processing.(37)

During the past years we have reviewed the facilities status from several points of view.

1. What is needed to complete the equipment requirements for a standard CMOS process?
2. What can we do to alleviate user crowding on certain apparatus?
3. How much maintenance is needed to keep a machine up?
4. What is the number of users a machines serves, to determine servicing priorities?
5. What-type of modifications are feasible considering need and resources?

1. Equipment for Standard CMOS Process

   After the start up of the new lab, we have slowly acquired all necessary equipment for CMOS processing and retired "make-do" and old systems. We are still in need of an essential aluminum plasma etcher, the lack of which limits research in sub-micron devices.

2. Reducing Crowding and Avoiding Conflicts

   The expansion of sensors research placed heavy demand and toll on the LPCVD furnaces. We have retrofitted a second tube for poly-silicon deposition to relieve crowding, and modified the nitride tube for low-stress film deposition. These low stress films are in great demand. Their popularity, coupled with the method used to deposit them, place a heavy burden on the furnace. Not only are the runs quite long (it takes about 5 hours of deposition time to grow a 1 μm thick low-stress film), but after that, the tube must be taken down for pump and exhaust manifold maintenance. We are in the process of looking at viable alternatives to accommodate the BSAC group.

3. Retiring Old Machinery

We have several old machines in the Microlab which are simply worn out. Maintaining these is an unending and demanding job and at some point we have to decide whether we can afford to do so any longer. If it is dedicated equipment, we ask the concerned PI's to replace it out of their own funds. If it is a generally used machine, the decision will be made by consensus of the users. The most recent example of this was the retiring of our 14 year old ion implanter. It was decided that using readily available and reliable outside services is more cost-effective than maintaining or replacing the old machine.

4. Servicing Priorities

Establishing priorities in servicing equipment used by different groups turned out to be a delicate balancing act. We were made aware on several occasions that a PI was unhappy with the service his group was getting; or, that the service is not in proportion to the support he is providing through his students in the lab. We are doing our best to satisfy every need; but sometimes certain jobs have to take lower priority. Every morning the list of problems reported on the computer is reviewed, and followed by a discussion of the most efficient way to deal with them. Inevitably, some jobs will not get done right away. It is not for lack of trying, but for lack of manpower.

5. In-House Modifications

One of the nice things about our lab, visitors often say, is the freedom students have in accessing equipment and in requesting changes to accommodate some special need. Flexibility is a key word here, and we are trying to do everything possible to help researchers. Equipment modification or upgrade is going on all the time. We have to be careful, however, that we are not drawn into complicated, long term jobs. While we may have the design capability to build systems, we certainly do not have the manpower to execute it without a great burden to the rest of the operation.

Computers

Computers in the Microlab are not only part of the facility, but also part of research projects. Computerization of the new lab started at the planning stage and communication lines and terminals were installed along with other equipment at the outset. Lab information and management software was developed and improved with constant use, and today they are indispensable, up-to-date tools for daily operation, administration, facilities maintenance and communication. The WAND program used by students includes on line processing and operating manuals, equipment on/off functions and reservation, equipment problem reporting, emergency procedures, available materials and chemicals and a visitors list. STAFF includes accounting, user information, technician's manuals, equipment logs, technician's job list, qualified user's list, inventory, vendors and purchasing.

Student projects within the Computer Integrated Manufacturing (CIM) program include designing of expert systems for processing; process modeling, characterization and diagnosis; equipment monitoring, diagnosis and control; facilities layout and utilities monitoring programs; speech input and synthesis. The staff is very much involved with CIM projects, starting with suggesting areas to explore, installing sensors, modifying hardware to allow for computer communication/control, testing of software and reporting results.

Besides allotting staff time to support these projects, CIM work must be coordinated with the other researchers in the lab to avoid disasters. For example, when the computer controlling the furnaces was modified to allow for SECS communication with the lab computers, the whole system had to be shut down placing everyone on hold. When it came up, all old programs had to be modified to run with he new hardware. All changes, no matter how well planned, are disruptive, but students and staff regard these as part of another research project.

Expanding the CIM program required upgrading of the main computer (a VAX 750) and changing to a distributed system comprised of several SUN workstations. The SUNs are connected through ETHERNET with the file server (a SUN 4/280, called 'Argon') maintaining a common data base (INGRES). We have 20 terminals and 4 workstations inside the lab, and 4 terminals and two workstations in the office.

User Training

The Microlab is a complete facility in which semiconductor devices and circuits are fabricated, beginning with layout, all the way through testing. The student study area is equipped with graphics terminals and a workstation for those who do not have layout capability in their own department. All lab users receive an account on the Microlab's computer, Argon, which is connected to the department and campus Ethernet. Equipment is shared by all users, except for those items that, by necessity, are dedicated to specific processes in three major categories - silicon, III-V compounds and superconductors. There are about 150 registered users; up to 30 usually work in the lab at any given time.

The facility is accessible with a key card 24 hours a day, 365 days a year, the only rule being that no one can work alone. Anyone wishing to work in the lab must take a one-day orientation course, presented by Microlab staff, which focuses on laboratory safety procedures. They must then pass a safety test before being granted admission to the lab. Students learn to operate equipment and to run processes from their fellow students. They become *qualified users* on a given machine after demonstrating to a *superuser* that they are sufficiently familiar with the operation of the instrument. Usually, two *superusers* are designated to a machine. They are senior graduate students whose research depends on the well being of that equipment. The *qualified* and *superuser* lists are updated immediately, and the new student is allowed to operate the machine independently.

We believe in allowing students as much freedom as possible, even at the expense of equipment breakdowns. They are encouraged to try out new ideas and are welcome to draw upon the experience of the staff, both in equipment and process technology.

Safety

The question of safety, from both occupational and environmental points of view, is constantly being addressed and kept in the forefront in the Microlab. The following programs illustrate our commitment to safety:

1. All students, staff and visiting scientists who work in the lab are required to take a lab orientation course, a major part of which concerns safety education. During this course the newcomers are instructed by staff on the safety procedures to be used in the lab, the equipment that is available to exercise safety, and where further information can be obtained. Currently, it is required that all users wear safety glasses at all times in the lab, and in addition, that they wear a face shield, acid

resistant gloves and apron when handling chemicals. This is being enforced by the staff of the Microlab.

2. We are in contact with the offices of Environmental Health and Safety and Occupational Health and Safety. They have inspected the Microlab on several occasions, after which we reviewed their observations and took corrective actions. Removal of hazardous waste is provided by the office of EH&S.

3. The Occupational Health Physician from the Occupational Health Service, visited our facility several times with other occupational and environmental health professionals as part of his efforts to educate his peers through seminars and continuing education courses. He uses the lab to demonstrate semiconductor industry safety practices.

We have a firm policy on areas of service that have a high risk associated with them. It forbids lab users from doing electrical wiring, changing gas cylinders and making modifications to equipment without permission from lab management.

1. Electrical wiring is done only by staff and it is done to California Electrical Code standards.

2. Gas cylinders are changed by staff trained in cylinder safety. Cylinders are always chained and toxic and corrosive cylinders are operated in vented steel cabinets. The Microlab has two SCBA (self-contained breathing apparatus) units and three staff members are certified to use them for rescue.

3. The lab has developed its own "low center of gravity" transportation carts for chemicals, and maintains a stringent policy for the transportation of chemicals.

4. Bulletins provided by vendors and bulletins from Environmental Health and Safety are routed with a sign off sheet to staff members. We also keep up-to-date MSDS (Material Safety Data Sheets) on all chemicals used in the lab. They are available to the lab users and a duplicate set is kept in the office.

We actively pursue safety in the lab and respond rapidly to any safety problems that we become aware of. Many of the steps we have implemented are new to the University and we are considered a model by the offices of Environmental Health and Safety and Occupational Health.

IV. Looking into the Future

In the few years since the new facility was constructed, Microlab users have produced numerous publications and research results that testify to the effectiveness of our cooperative approach. At the moment, our financial footing, although precarious, seems to be established. However, if we hope to continue to support teaching and research of the highest quality, we must seriously examine our position and identify its weak points. Those immediately obvious are the following:

1. We have no new development activity to speak of on the part of the staff. This means that we are falling behind industry standards and soon we will be unable to support our students' efforts in a meaningful way.

2. We have no program in place to provide new equipment and staff help for advanced projects.

3. We have very limited funds to upgrade/overhaul/replace current equipment as these become worn out and obsolete. Within 3-4 years, we estimate, the lab will be obsolete.

4. Although we now have a balanced budget, we will not be able to maintain it for long. We are counting on increased revenue to offset cost increases, but, with current utilization of about 75%, there is not much space to grow. Increasing recharge rates would be another option; however, this would be counter-productive. Our cautious estimate says that available research grants will not grow at the same rate as expenses, and increased rates would simply exhaust those funds faster. We can expect running into deficit again, within 2-3 years, merely maintaining our current mode, which is not satisfactory.

V. Conclusions

It has been our experience that maintaining a working university laboratory, where integrated circuits can be fabricated, requires substantial commitment on the part of the faculty. There must be a group of PI's whose research depends on a working lab, who will serve as its major supporters. There must be a critical mass of technical staff who maintain the lab and provide continuity for the changing student body. An advanced lab, such as ours, cannot be financed fully from recharge rates; even when the user base is as wide as ours (153 lab users from 46 PI's). If we are to maintain excellence and remain up-to-date with current technologies, other sources of support must be found.

Biographies

Ping-Keung Ko received the Ph.D. degree in electrical engineering in 1982 from the University of California at Berkeley.

He spent 1982 and 1983 at Bell Laboratories, Holmdel, NJ, working on high-speed MOS technologies. In 1984 he joined the University of California at Berkeley where he is an Associate Professor of Electrical Engineering and Computer Sciences. He has been the Faculty-in-Charge of the Microfabrication Facility since 1984. His current research areas include high-speed VLSI technologies and devices, and MOS device modeling for circuit simulation. He has authored or co-authored one book and over 90 research journal articles.

Katalin Voros graduated from the Drexel Institute of Technology (Philadelphia) in 1966 with a B.S. degree in physics. She gained extensive experience while working as a process engineer for Philco-Ford Microelectronics (bipolar ICs), Solid State Scientific, Inc. (RF transistors, CMOS circuits), and Microwave Semiconductor Corporation (high frequency power transistors). Her primary assignments were in process support and development, material and equipment evaluation, device testing, failure-mode analysis, yield enhancement and product engineering. She joined RCA's David Sarnoff Research Center in Princeton, New Jersey in 1980, working as an associate member of technical staff in the high-density bulk CMOS (SRAM) development group.

In 1983, Ms. Voros came to the EECS Department at UC Berkeley as a master's student working with Professor W. G. Oldham. After receiving her Master of Science degree, she was hired in January 1985 as a process development engineer assigned to establish a baseline CMOS process in the Microlab. She organized and trained a process group of four who are well versed in all aspects of semiconductor processing. She became manager of the Microlab in December of 1986.

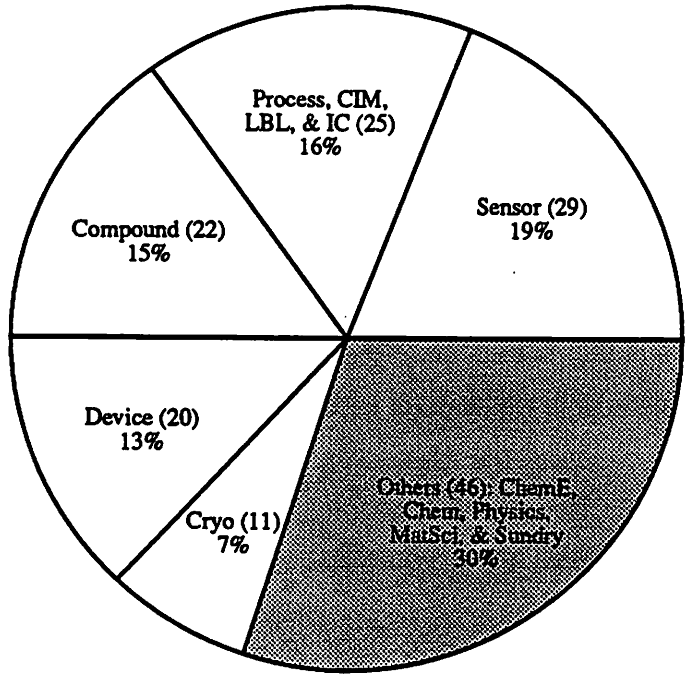

Figure 1. Number of Microlab Users from Each Research Group, September 1989

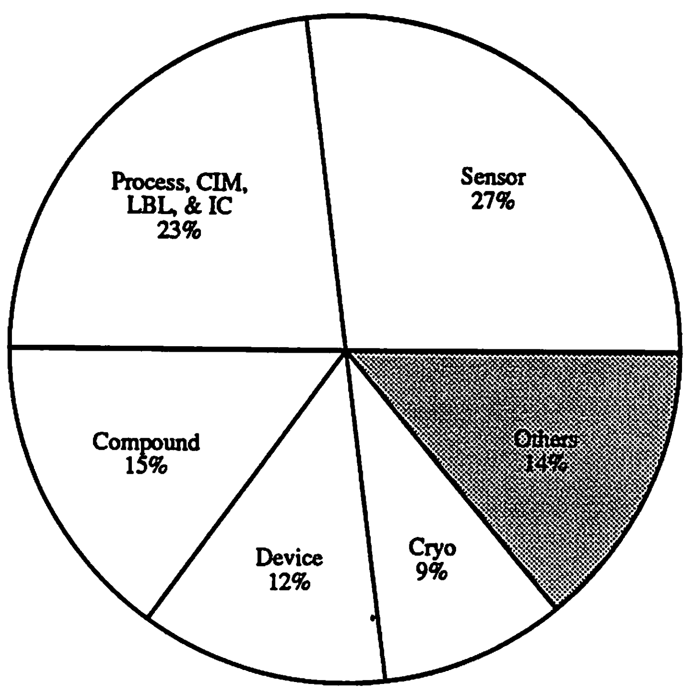

Figure 2. Distribution of Operating Income from Research Groups, FY 88/89

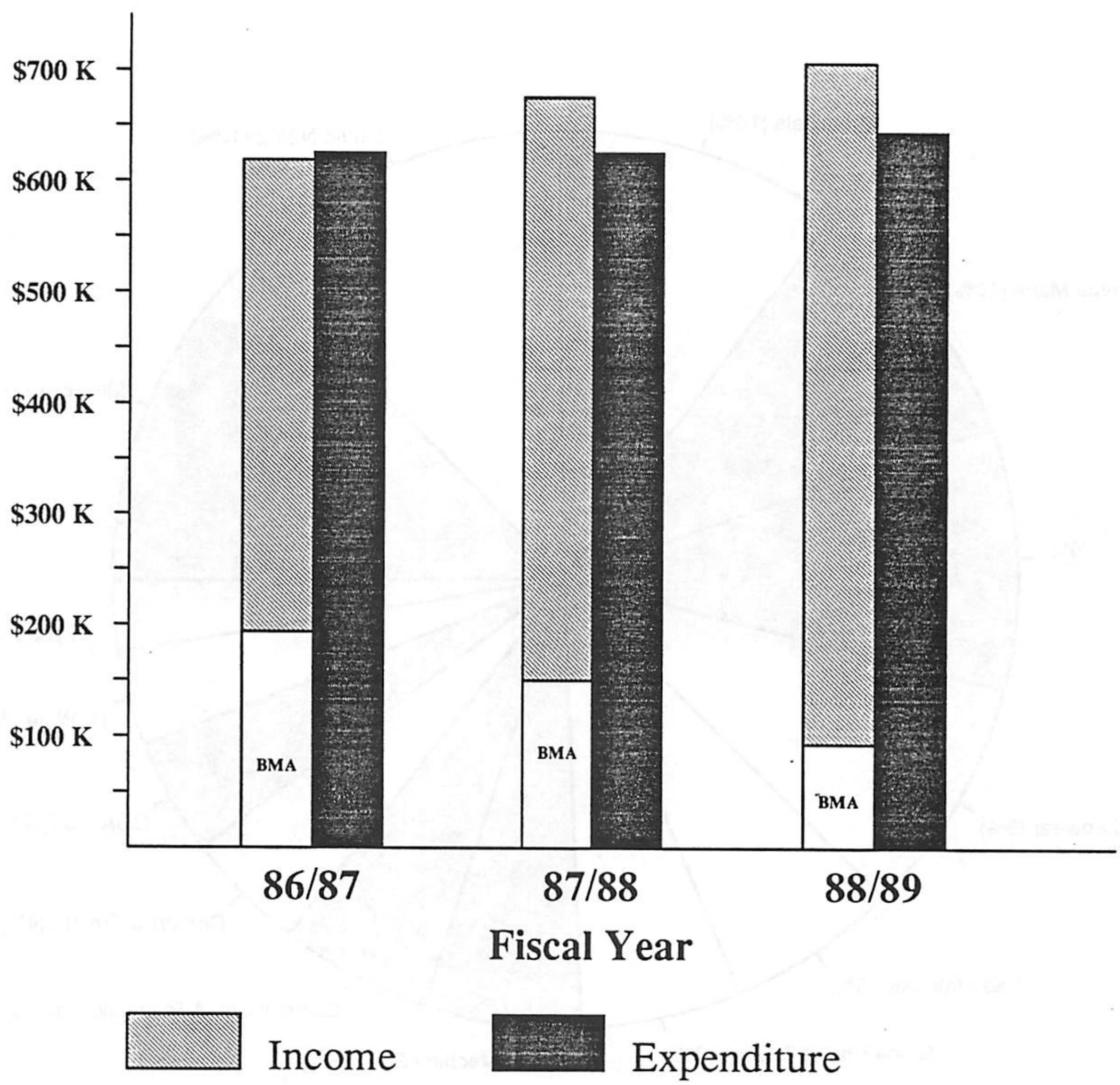

Figure 3. Microlab Operating Income and Expenditures

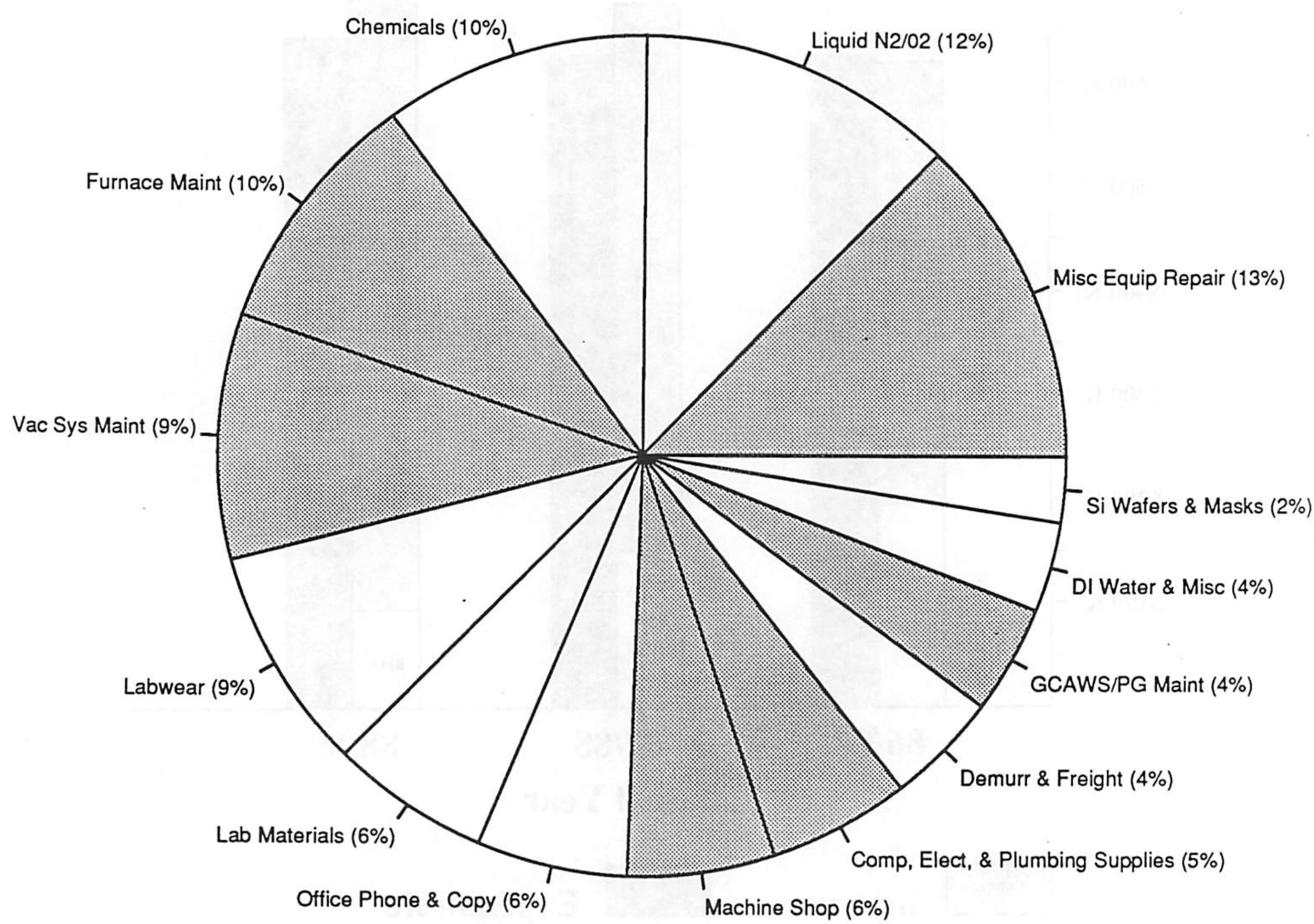

Figure 4. Breakdown of Expenditures for Supplies, FY 88/89
(Salaries not included, only cost of materials and replacement parts; direct expenses paid by Microlab)

Katalin Voros
Laboratory Manager
Senior Development Engineer

Ping K. Ko
Faculty-in-Charge

MAINTENANCE

Robert Hamilton
Maintenance Supervisor
Associate Development Engineer

Phillip Guillory
Development Technician V

Steve Hoagland
Principal Electronics Technician

Jules Nagy (0.5)
Student, Engineering Aide

Robert Norman
Development Technician V

James Parrish
Principal Laboratory Mechanician

Evan Stateler
Development Technician V

ADMINISTRATION

Rosemary Spivey
Administrative Supervisor
Administrative Assistant II

Susan Kellogg Smith (0.5)
Purchasing Assistant I

James Hopkin (0.5)
Computer Support
Student, Engineering Aide

PROCESS

Robin R. Rudell
Process Supervisor
Staff Research Associate III

Tom Booth
Staff Research Associate II

Marilyn Kushner
Staff Research Associate I

Christine Saunders (0.5)
Student, Laboratory Helper

ASSOCIATED RESEARCH

STAFF	RESEARCH/PRINCIPAL INVESTIGATOR
Kim Chan (0.5) *Staff Research Associate II* **Richard Hsu** *Associate Development Engineer*	**Deep UV Lithography** A. R. Neureuther W. G. Oldham
David Hebert *Associate Development Engineer*	**Cryoelectronics** T. VanDuzer
Jongnam Kim *Staff Research Associate II*	**Berkeley Sensors and Actuators Center** R. Howe, R. Muller, R. White
Lauren Massa *Programmer/Analyst II*	**Computer Integrated Manufacturing** D. A. Hodges, C. J. Spanos

Figure 5. Microlab Staff

Charges to PI's in FY 88/89

Number	Advisor	Total Paid to Microlab	Access	Lab	Staff	Equip	Supplies
1	oldham	75445.06	7317.49	54727.83	2104.60	11295.14	10697.72
2	muller	60481.77	7610.72	33353.67	1762.69	17754.70	12065.32
3	vanduzer	50096.62	9313.94	34768.58	1392.35	4621.75	7550.98
4	white	38467.93	7095.92	21629.30	766.27	8976.44	5645.37
5	sundry	31532.60	2405.54	9378.44	9574.04	10174.57	8189.83
6	howe	31233.71	4346.26	15995.79	1804.58	9087.08	3890.92
7	ko	28964.59	4166.70	12474.52	3837.09	8486.28	6976.51
8	hu	28938.04	6405.08	11461.16	700.07	10371.74	5733.03
9	wang	27487.88	7734.55	18396.98	373.57	982.78	6779.01
10	whinnery	21126.81	2811.12	13659.79	765.99	3889.92	2860.98
11	hess	20919.04	3551.94	14942.26	397.57	2027.27	2103.81
12	cheung	18801.19	3288.34	10465.10	685.97	4361.78	1791.29
13	clarke	15263.50	4490.46	9797.60	326.46	648.98	908.30
14	neureuther	14704.06	4348.48	6925.98	748.85	2680.76	3888.70
15	schwarz	13961.19	3272.42	8904.29	670.47	1114.02	1315.32
16	nygren	8670.68	1603.26	2646.95	913.63	3506.85	765.89
17	weber	8491.20	2916.82	5343.86	101.52	129.00	349.94
18	smith	7976.48	4103.02	3836.77	26.40	10.29	6881.32
19	hodges	4946.45	3412.18	1289.13	52.80	192.34	445.94
20	packard	4116.98	1603.26	2294.72	44.32	174.68	253.40
21	majda	3693.98	838.56	2381.10	164.16	310.17	641.14
22	morris	3431.32	1677.12	1128.45	333.01	292.74	784.10
23	soane	2812.48	1545.32	1112.14	99.72	55.30	74.67
24	searcy	2230.72	1397.60	824.42	6.60	2.10	66.99
25	perez-mendez	1818.65	830.60	293.49	642.09	52.46	40.26
26	richards	1737.79	582.92	884.58	99.55	170.73	195.66
27	glaeser	1268.02	632.90	506.62	8.80	119.70	7.08
28	shen	1038.98	838.56	200.42	0.00	0.00	0.00
29	townes	858.16	764.70	93.46	0.00	0.00	5.00
30	bednarski	690.13	295.44	36.96	227.48	130.25	0.00
31	radke	656.58	616.98	39.60	0.00	0.00	5.64
32	pimentel	633.98	616.98	17.00	0.00	0.00	0.00
33	zettl	622.55	616.98	5.57	0.00	0.00	0.00
34	ritchie	607.39	543.12	64.27	0.00	0.00	0.00
35	denn	604.96	485.18	119.78	0.00	0.00	35.27
36	tobias	538.15	485.18	52.97	0.00	0.00	0.00
37	lewis	488.18	419.28	62.40	4.40	2.10	79.19
38	malina	456.52	0.00	0.00	321.12	135.40	183.00
39	sadoulet	420.60	147.72	272.88	0.00	0.00	68.97
40	lbl	353.38	353.38	0.00	0.00	0.00	0.00
41	evans	329.50	329.50	0.00	0.00	0.00	0.00
42	lieberman	303.31	0.00	0.00	303.31	0.00	10.00
43	mei	265.64	221.58	44.06	0.00	0.00	0.00
44	spanos	73.86	73.86	0.00	0.00	0.00	0.00
45	walton	65.90	65.90	0.00	0.00	0.00	0.00
46	brodersen	53.40	0.00	0.00	53.40	0.00	0.00
	Net Cost	537679.81	106176.85	300432.84	29312.89	101757.30	91290.55

Table 1

Microlab Financial Summary
Fiscal Year 88/89

Expenditures

Supplies & Expenses	$351,459.66
Sal. & Ben. (9 FTE)	$292,362.19
Total	**$643,821.85**

Income

ML Income	$614,141.32
BMA Cont.	$94,051.28
Total	**$708,192.60**

Total Expenditures, FY 88/89	**$643,821.85**
Total Income, FY 88/89	**$708,192.60**
Debt Recovery, FY 88/89	**$64,370.75**
Total Debt at the End of FY 88/89	**$336,816.73**

Table 2

Supplies and Expenses for FY 88/89

Item	OC	Expenses	Income from Sale of Materials	Paid by Lab
LN/O2	8034	34537.70	3796.89	30740.81
Chemicals	8020	26493.09	648.91	25844.11
Tylans Maint./Spec. Gases	8044	24171.29		24171.29
Vac Syst/Pump Maint.	8029	23856.85		23856.85
Misc Equip Maint./Spec. Gases	8026	22623.17		22623.17
Machine Shop	7215	14424.27		14424.27
Labwear	8022	23479.78	1817.68	21662.10
GCAWS/Pattern Generator	8047	10491.28		10491.28
Lab Materials	8062	24712.08	15195.27	9516.81
Gas Cylinder Demurrage	8054	7467.00		7467.00
Telephone	4100	6077.92	302.76	5775.16
Computer Maintenance	8050	4746.59		4746.59
Plumbing & Hardware	8023	4641.97		4641.97
Electrical Supplies	8024	4282.29		4282.29
Office Supplies	8070	3986.73		3986.73
Miscelaneous	8000	3807.04		3807.04
DI Water	8025	3797.42		3797.42
Facilities	8045	3634.23		3634.23
Freight	3000	3442.68		3442.68
Si Wafers	8027	39139.58	35816.71	3322.87
Masks	8028	10750.64	7709.39	3041.25
LAM 1&2 Maint/Spec. Gas	8046	2747.19		2747.19
Film	8031	10541.31	8421.77	2119.54
Copy Machine	5305	2048.59		2048.59
Tools	8051	1686.61		1686.61
Ion Implanter	8048	1653.03		1653.03
CSSEM	8049	1355.86		1355.86
Sinks	8021	1316.58		1316.58
Mailing	4400	1028.62		1028.62
PTherm/Spec. Gases	8052	841.90		841.90
Parking	7200	734.11		734.11
Cent Dup	7000	619.36		619.36
Courses	8063	545.00		545.00
Travel	2000	418.20		418.20
Drafting	7214	365.56		365.56
Books	6200	224.92		224.92
Special Orders	8053	24774.22	24774.22	0.00
Total Supplies & Expenses		**$351,459.66**	**$98,483.60**	**$252,976.06**

Table 3

Name	Fund	Advisor	Gross User Total	Access	Lab	Staff	Equip	Supplies
Robert Chu	442427-55091 (Various)	ko	103.02	73.86	29.16	0.00	0.00	0.00
Tom Garfinkel	442427-55091 (Various)	ko	73.86	73.86	0.00	0.00	0.00	0.00
Bhusan Gupta	482427-25304 (JSEP)	ko	314.46	73.86	0.00	213.60	27.00	0.00
Kelvin Hui	442427-59951 (VDON)	ko	73.86	73.86	0.00	0.00	0.00	0.00
Min-Chie Jeng	442427-52055 (SRC)	ko	73.86	73.86	0.00	0.00	0.00	0.00
James Moon	482427-25304 (JSEP)	ko	2731.51	73.86	1000.00	13.35	1000.00	644.30
Michelle Wong	482427-25304 (JSEP)	ko	1319.06	73.86	772.20	8.90	372.60	91.50
Gross Cost		ko	4689.63	517.02	1801.36	235.85	1399.60	735.80
Kaveh Niazi	442427-22416 (DOE)	lieberman	73.86	73.86	0.00	0.00	0.00	0.00
Gross Cost		lieberman	73.86	73.86	0.00	0.00	0.00	0.00
Charles Goss	441230-21702 (CHEM)	majda	73.86	73.86	0.00	0.00	0.00	0.00
Gross Cost		majda	73.86	73.86	0.00	0.00	0.00	0.00
Tom McKnelly	442456-54334 (MATSC)	morris	74.94	73.86	1.08	0.00	0.00	0.00
John Sanchez	442456-54334 (MATSC)	morris	212.95	73.86	128.52	0.00	0.00	10.57
Gross Cost		morris	287.89	147.72	129.60	0.00	0.00	10.57
Rolfe Anderson	442427-28757 (LLL)	muller	761.57	73.86	555.84	0.00	79.56	52.31
Reid Brennen	442427-59989 (SENSORS)	muller	73.86	73.86	0.00	0.00	0.00	0.00
Young-Ho Cho	442427-59989 (SENSORS)	muller	130.02	73.86	56.16	0.00	0.00	0.00
Sensors FAX	442427-59989 (SENSORS)	muller	322.78	0.00	0.00	0.00	0.00	322.78
Long-Sheng Fan	442427-59989 (SENSORS)	muller	285.96	0.00	102.96	0.00	0.00	183.00
Sang Han	442427-59989 (SENSORS)	muller	239.58	73.86	137.88	0.00	0.00	27.84
Chang-Jin Kim	442427-59989 (SENSORS)	muller	73.86	73.86	0.00	0.00	0.00	0.00
Eun Sok Kim	442427-59989 (SENSORS)	muller	1607.61	73.86	1000.00	0.00	517.32	16.43
Jongnam Kim	442427-59989 (SENSORS)	muller	1313.61	73.86	1000.00	0.00	222.48	17.27
Abraham Lee	442427-59989 (SENSORS)	muller	74.58	73.86	0.72	0.00	0.00	0.00
Carlos Mastrangelo	442427-59989 (SENSORS)	muller	2584.46	73.86	1000.00	0.00	1000.00	510.60
Yu-Chong Tai	442427-59989 (SENSORS)	muller	373.50	73.86	159.12	40.05	54.72	45.75
Gross Cost		muller	7841.39	738.60	4012.68	40.05	1874.08	1175.98
Richard Ferguson	442427-05397 (SEMATECH)	neureuther	115.98	73.86	42.12	0.00	0.00	0.00
Andy Neureuther	442427-05397 (SEMATECH)	neureuther	120.03	73.86	25.92	0.00	0.00	20.25
Edward Scheckler	442427-05397 (SEMATECH)	neureuther	80.70	73.86	6.84	0.00	0.00	0.00
Nelson Tam	442427-57377	neureuther	126.84	73.86	15.48	26.70	10.80	0.00
Kenny Toh	442427-05397 (SEMATECH)	neureuther	73.86	73.86	0.00	0.00	0.00	0.00
Gross Cost		neureuther	517.41	369.30	90.36	26.70	10.80	20.25
Steve Holland	442427-26835 (LBL)	nygren	2168.39	73.86	1000.00	0.00	1000.00	94.53
Gross Cost		nygren	2168.39	73.86	1000.00	0.00	1000.00	94.53
Ginetto Addiego	442427-05397 (SEMATECH)	oldham	237.86	73.86	0.00	0.00	0.00	164.00
Mark Callicotte	442427-05397 (SEMATECH)	oldham	609.18	73.86	535.32	0.00	0.00	0.00
Carl Galewski	442427-52055 (SRC)	oldham	1821.02	73.86	1000.00	534.00	201.24	11.92
Diane Hoffstetter	442427-05397 (SEMATECH)	oldham	2126.07	73.86	1000.00	26.70	1000.00	25.51
Richard Hsu	442427-05397 (SEMATECH)	oldham	783.78	73.86	709.92	0.00	0.00	0.00
Jen Chung Lou	442427-59987 (IBM)	oldham	2542.25	73.86	1000.00	57.85	674.28	736.26
Loni Manske	442427-05397 (SEMATECH)	oldham	104.10	73.86	30.24	0.00	0.00	0.00
William Partlo	442427-05397 (SEMATECH)	oldham	1199.13	73.86	1000.00	0.00	0.00	125.27
Christopher Spence	442427-05397 (SEMATECH)	oldham	1446.16	73.86	1000.00	66.75	27.00	278.55
Gross Cost		oldham	10869.55	664.74	6275.48	685.30	1902.52	1341.51
Ajay Amar	444010-21378 (PHYS)	packard	73.86	73.86	0.00	0.00	0.00	0.00
Gross Cost		packard	73.86	73.86	0.00	0.00	0.00	0.00
Cho Gyuseong	442427-26863	perez-mendez	112.02	73.86	38.16	0.00	0.00	0.00
Gross Cost		perez-mendez	112.02	73.86	38.16	0.00	0.00	0.00
Micheal Nahum	449580-23279 (SSL)	richards	73.86	73.86	0.00	0.00	0.00	0.00
Scott Sachtjen	449580-23279 (SSL)	richards	317.44	73.86	242.28	0.00	0.00	1.30
Simon Verghese	449580-23279 (SSL)	richards	444.85	73.86	50.76	106.80	156.60	56.83
Gross Cost		richards	836.15	221.58	293.04	106.80	156.60	58.13

Table 4. Sample Page from Monthly Statement for PI's

Mask Making

- GCA 3600 Pattern Generator
- APT Chrome Mask Developer
- APT Emulsion Mask Developer
- 10:1 Mask Reduction Camera
- Ultratech Mask Duplicator

Photolithography

- Ultratech 900 Wafer Stepper (modified)
- GCA 6200 10X (4") Wafer Stepper
  - with Excimer laser light source
- Canon 4X Wafer Stepper
- Kasper Contact Aligner
- 2 Headway Spinners
- Eaton 4" Wafer Trak
- MTI 4" Developer/Stripper
- Silylation System
- 2 Bake Ovens

Wafer Cleaning

- 12 Semifab Wet Process Stations
- 2 Dexon Wet Process Stations
- 2 Fluorocarbon 4" Spin Dryers
- DI Water: Continental Water RO System

Thermal Processing and CVD

- Tylan/Tytan-II Furnaces
  - 11 general purpose tubes
  - 5 LPCVD tubes
- Lindberg Diffusion Furnaces
  - 9 tubes for 2" wafers
- 2 AG Heatpulse RTA Systems
- 2 Liquid Phase Epitaxy Furnaces

Thin-Film Systems

- CPA 3-target Sputtering System
- MRC Sputterer for zinc oxide
- Varian NRC WE-04 Evaporator
- Varian 936 Leak Detector
- Veeco 401 Evaporator
- Veeco 775 Evaporator
- Veeco Microetch Ion Milling System
- Perkin-Elmer Randex 3-Target Sputterer
- Davis and Wilder Evaporator
- Gartek 3-Target Sputterer with ESCA
- S-Gun (3) Sputtering System
- 2 Hummers for metal coating SEM samples

Plasma Systems

- 2 Lam Autoetch Systems (4")
- Technics Plasma Etching System
- 2 Technics Plasma Deposition Systems
- Technics Microstripper
- PlasmaTherm RIE System
- Semi-Group Plasma/RIE System
- Barrel Etcher for 2" wafers

Packaging

- Tempress Wafer Saw
- Westbond Ultrasonic Bonder

Analytical Equipment

- 6 High-Power Microscopes
  - 1 with color TV monitor, 1 with 35 mm
  - Olympus auto-exposure camera
- Reichert Polylite with Nomarski
- Vickers Image-Shearing Microscope
- Nanometrics Nanoline IV
- Nanometrics Nanospec AFT
- Nanometrics Cwikscan II SEM
- Nanometrics Deep UV Microspectrophotometer
- Hitachi S-310A SEM
- Gaertner Ellipsometer with HP compcon
- Tencor Alpha-Step Profilometer
- Tencor Alpha-Step 200 Auto. Profilometer
- Tencor Sonogage rt2 Resistivity Meter
- Tencor Flatgage
- Prometrix Resistivity Mapping System
- Signatone Manual 4-Point Probe with HP inst.
- Signatone C-V Probe Station with HP compcon
- Signatone I-V Probe Station with HP compcon
- Scientech Electronic Balance
- Perkin-Elmer PR Dev. Rate Monitor
- VG Instruments Residual Gas Analyzer

Table 5. Microlab Equipment

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Table 6. Representative List of Publications