new science, much of the work with it so far has been exploration for potential applications—what Robert C. Waag of the University of Rochester Medical School characterizes as "turning over rocks and looking for diamonds." The search has been fruitful for biological samples because they can be viewed in a natural state: they do not need to be exposed to a vacuum, as is necessary for electron microscopy, or stained to increase contrast, as is necessary in optical microscopy. Differences in tissue elasticity and density generally provide more than enough contrast.

Investigators such as Waag and William D. O'Brien, Jr., of the University of Illinois at Urbana-Champaign have been looking at various types of organs with a 100-MHz SLAM to determine what factors are responsible for image production. They have found that the greatest attenuation of sound is produced by collagen, a major structural component of many kinds of tissue. O'Brien has been able to measure the velocity of sound in a single strand of collagen—a feat not possible with other techniques—and thinks his results will provide useful information both for modeling ultrasonic imaging and for better understanding structural tissues. Waag has also shown that the technique can be used to distinguish between varying states of fibrosis in lung tissues.

Reginald C. Eggleton of the University of Indiana Medical School is using a 100-MHz SLAM to examine muscle tissues. He is able, for example, to image an entire fetal mouse heart while it is functioning in a tissue culture system (Fig. 4). He is thus able to study such things as the effects of cardioactive drugs on internal valves; these valves are not visible in an optical microscope. By focusing attention on only one line of the image on the cathode-ray tube, he is also able to monitor the time course of contraction of various parts of the heart. In particular, he has been able to delineate the pathway of nerve impulses following stimulation of contraction by a pacemaker. He has also examined other muscle tissues, such as the frog sartorius muscle, and has been able to measure elasticity both along the length of the muscle and perpendicular to it. He hopes to be able to relate this

Speaking of Science

Microelectronics: Defense Department Looks to the 1980's

Beginning this fall, the Department of Defense is launching a $150 million effort to develop the microelectronics technology needed for its guidance, surveillance, and communications systems of the mid-1980's and beyond. To be spent over a 6-year period, this outlay will go to a coordinated tri-service program aimed at producing very high speed microelectronic circuits. In addition, a smaller amount will go to a separately managed Advanced Research Projects Agency (ARPA) project with the same general goal that emphasizes high-risk, longer-range research. Because the annual amount under both projects is small compared to that already spent by the semiconductor manufacturers on their own research and product development, the money will be spent in ways calculated to stimulate the industry to advance its timetable for the development of high-speed signal processing and computation circuits by 5 years. (For a look at the impact of military electronics, see News and Comment, p. 1102.)

Much has been made in the last 2 years of the Japanese threat to the long-held U.S. supremacy in microelectronics. The next generation of ultraminiature electronics goes by the moniker of VLSI—for very large scale integrated circuits; Japanese companies are now parlaying both rising sales in the worldwide electronics market and a substantial amount of financial support from their government into an effort to be first in the race to VLSI. But it is not the potential economic threat from Japan that has prodded DOD into action. Instead, it is an increasing divergence between military needs in the next decade and what the U.S. semiconductor industry produces for commercial applications that is said to be the driving force. A second major factor is that what is purported to be a rapidly growing Soviet capability in military microelectronics has eroded a once substantial U.S. lead.

The Soviets have frequently been pictured, at least in the popular press, as being outclassed when it comes to microelectronics. Two years ago, when a defecting pilot landed a MiG-25 (Foxbat) in Japan, newsmagazines gleefully reported that the so-called superaircraft contained only vacuum-tube electronics and no solid-state, let alone microelectronic, circuits. If nothing else, the reputed increases in accuracy of Soviet missiles belie this conception, but the subject is classified and little specific information is publicly available.

In the meantime, the "signal processing intensive" electronics systems of the U.S. military will require the computational power of today's supercomputers to be packed into configurations that are ten times lighter, smaller, and less power-consuming than present systems. Such characteristics will require new microelectronics circuits that are simultaneously faster and more miniaturized than existing devices. One goal is to increase by 100 times the available rates of computation for each microelectronic chip.

The new DOD programs, called VHSI for very high speed integrated circuits, are intended, says Leonard Weisberg of the Pentagon's defense research and engineering office, to develop a few circuit designs with broad functional capabilities that satisfy a large number of the military's needs. At present, military microelectronic circuits are often custom designs. A second goal is to have available military-qualified versions of the new circuits before commercial versions, a reversal of the present pattern. Moreover, adds Richard Reynolds of ARPA, many military systems require a performance far beyond that envisioned for commercial uses even in the distant future. In short, since the military accounts for only about 7 percent of the U.S. semiconductor manufacturers' market, the industry is not rushing to develop on its own the technology the military has to have but cannot purchase in sufficient quantity to make its manufacture profitable.

The tri-service portion of the new microelectronics effort will be partitioned into three areas. The first of these concerns the photolithographic process whereby the intricate patterns that together make up a microelectronic circuit are

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elasticity to the number of cross-links between actin and myosin filaments.

Kessler, who is now president of Sonoscan, and Donald E. Yuhas of that company have also looked at heart tissues. They have found that the technique can readily distinguish between healthy tissue and tissue that has suffered an infarct. They have also shown that internal features of fruit fly larvae can be distinguished by acoustic microscopy; these features are not visible in an opitcal microscope.

Acoustic microscopy should also be useful for studying blood cells, Quate says, because variations in their elasticity are quite important. Newly produced erythrocytes are very elastic, but much of this elasticity is lost during the 120 days of their normal existence. It should thus be possible to determine the age of the cells by acoustic microscopy; this could be useful, for example, in studies of certain types of anemia in which erythrocytes are degraded more quickly than normal. The technique should also be useful in studies of sickle cell anemia, in which the cells are much less elastic than normal. Elasticity may also be an important characteristic of malignant cells, which have an enhanced ability to move through narrow, constricted channels during metastasis. Already, Quate says, there is evidence that the velocity of sound is greater in malignant tissues than in healthy ones (Fig. 5).

In one other noteworthy study, Hemantha K. Wickramasinghe of Quate's laboratory has examined Chinese hamster ovary cells with the 1-GHz SAM. He has shown that it is possible to distinguish between cells that have doubled their DNA content and are ready to divide and those that have not. This can be accomplished with conventional radioactive labeling, but the procedure is tedious and time-consuming. There are many potential applications, Quate notes, where it would be useful to detect incipient cell division.

Perhaps the greatest interest in acoustic microscopy now, however, involves its applications in materials science. Those few centers that have acoustic microscopes have been deluged with samples from manufacturers of, for example, semiconductors, circuitboards, in-

delineated. At present, for example, the pattern is transferred onto the semiconductor by means of 4000-angstrom light that is shined through a mask containing the desired pattern onto a photosensitive polymer overlaying the semiconductor chip. Future processes could use vacuum-ultraviolet, x-ray, electron, or ion beams to make patterns with features having dimensions of as small as 0.5 micrometer as compared to about 5 micrometers now.

A second part of the program will be devoted to design and testing of the circuits themselves and of the computer programs that will direct their operation. It is a mammoth job, for example, to arrange from 10,000 to 100,000 devices on a single chip of semiconductor in such a way that they function efficiently. A particular goal will be to minimize the need for customized designs because microelectronics circuits are expensive to design but cheap to manufacture. The microprocessor boom is one result of the same pressure on commercial electronics. (A microprocessor is a general-purpose circuit that can be made to suit any user's needs by writing a specific computer program to control its operation without having to redesign the circuit.) But planned microprocessors will be many times too slow for military systems of the next decade.

The third part of the program entails the actual fabrication of advanced circuits. A principal problem in all microfabrication is increasing the yield—that is, the ratio of the number of circuits produced that have no defects to the total number produced. The VHSI program thus is shooting for a pilot plant facility that can produce quantities of two advanced types of devices: computer memory chips containing 2 million bits of information and logic chips that can execute 1 million instructions per second. The chips must meet military specifications.

Each of the services will spend about $7 million the first year. A possible major stumbling block yet to be overcome is that the funding does not come from new money added to the fiscal year 1979 budget now wending its way through Congress. Rather, the indicated sum is to be reprogrammed by each of the services—that is, the money must be accumulated by cutting or reducing already approved R & D. As one observer noted, "an awful lot of heartburn will be created in making this pot." A new Pentagon wrinkle is that, while the money for the VHSI program is to come from the services, the allocation of the dollars and program direction will be by way of the defense research and engineering office.

The situation at ARPA is more salubrious in this regard. In addition to existing advanced microelectronics research, new components will be added dealing with basic materials and fabrication technology and with circuit design. For the first year, about $3 million will go to the new projects, but the amount is from funds reserved for new programs.

The present relationship between the DOD and the semiconductor industry seems a curious turnabout. Once upon a time, government and industry were locked in a synergistic embrace that, if it did not make microelectronics possible, greatly speeded its development. Not only research funding, but infusions of capital for purchasing the equipment needed to fabricate microelectronics circuits and the providing of a market for the circuits produced were essential to the rapid growth of the industry (*Science*, 18 March 1977, p. 1107).

Now some in the semiconductor industry are taking exception to elements of the Pentagon's thinking, although the specifics of the VHSI project have yet to be made public. The claim is that, by concentrating on its own unique requirements, the Pentagon is acting like the proverbial tail that tries to wag the dog. Overriding all concerns, however, is that over the Japanese VLSI challenge.

While the VHSI project is not overtly intended to help the U.S. semiconductor industry meet this test, it has the potential to do just that because the technology overlap between VHSI and VLSI is nearly 100 percent. Moreover, the government will be helping those companies selected to work on the project to develop some advanced fabrication equipment and DOD will be the first major customer of the new circuits. It could be a repeat of a familiar story.

Such an outcome would please the industry no end; the fear is that, if the program focuses on specific, even exotic, circuits rather than on advancing the health of the industry by developing new technology, the VHSI project will end by helping no one very much.—ARTHUR L. ROBINSON