MICROELECTRONICS
AND NEURAL PROSTHESES

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The realization of effective neural prostheses requires both understanding of the neural physiological substrate of the function and the availability of hardware, stimulation electronics, electrodes, sensors, and information processing electronics, to execute the required function. Microelectronics, especially custom and semicustom integrated circuits, have effectively removed some of these barriers. Particularly in the area of implantable stimulation electronics, custom integrated circuits and advanced hermetic packaging techniques have been developed so that it is possible to make very small, long-lived multichannel stimulation systems. Similarly, the availability of low-power CMOS microprocessors, logic and memory components makes it possible to execute complex information processing in small, low-power portable systems. The principal technological bottlenecks in neural prostheses remain stimulation electrodes and physiological sensors. The techniques underlying microelectronic photolithographic fabrication may also make possible the "solution" of the electrode and sensor problems. In our auditory prosthesis project, we have photolithographic electrode arrays of both rigid and flexible character now nearing operational status. These electrodes are probably generalizable to a fairly wide number of prostheses applications. A number of sensors, especially those of pressure, motion and temperature, are also yielding to photolithographic fabrication. The sensor problem, however, for such physiologic parameters as ionic concentration remains the most difficult to conquer. Examples and illustrations of the state-of-the-art in these areas, as achieved by microelectronic techniques, will be given.

INTRODUCTION

A closed-loop control system, physiologic or otherwise, always has three basic system components. There must be a sensor, which detects the state of the system to be controlled, usually by transducing some fiduciary parameter into an electrical signal. There must be a signal processing unit, which compares the sensed parameter to a reference, and generates an error signal whose sign and magnitude reflect the departure of the controlled
system from the desired state. There must be an actuator, which applies the error signal to the controlled system in such a fashion as to move the system toward the desired state.

In this paper we will discuss the impact of microelectronics upon these three control system components, especially with reference to neural prostheses. Neural prostheses are the class of physiologic control systems best matched to the special characteristics of microelectronics, and so have provided the impetus for most of the application of microelectronics to physiologic systems.

RELEVANT CHARACTERISTICS OF MICROELECTRONICS

The insatiable needs of the computer industry for densely packed, low-cost, low-power components has driven the semiconductor industry to develop active electrical circuits of incredible performance and size. A comparison of the physical size scale of semiconductor memory or logic with the physical size of neural networks can be obtained by reference to Fig. 1. This figure is comprised of two superimposed microphotographs, taken at the same magnification. The large objects in the foreground are neurons of the human motor cortex. The background, which looks something like wallpaper, is a portion of an Intel 4-kbit random access memory. The memory cell size is visible in the repeat dimensions of the wallpaper. The cell density of the semiconductor memory is at least two orders of magnitude higher than that of the human nervous tissue. To convert the

FIGURE 1. Superimposed microphotograph, to same scale, of cortical neurons and semiconductor memory chip (Intel 4 kbit RAM).