I. INTRODUCTION

During the past decade the integrated microcircuit has been brought from a laboratory dream into a production reality. The development of this technology came about as a series of incremental improvements stimulated by active competition among a relatively large number of firms, and an eager marketplace. It is thus not surprising that a remarkable technology has emerged and that it has grown in an incremental fashion.

Today's microcircuit capability has envolved out of incremental improvements to the existing technology. But it is possible that the technology may soon reach a cul-de-sac, i.e., that further incremental steps will not lead to further marked improvements in economy or performance, even though such improvements are possible by other means. If this is so, and there is abundant evidence to support this belief, entirely new processes must be implemented, processes that may be very difficult for a firm competing in today's market to adopt. Just as the economically outmoded World War II steelmaking technology still persists in the United States today because newer, more economical methods are not readily accessible to an industry already heavily capitalized, so our current investment in particular fabrication methods may prove a detriment as circuit technology progresses to submicron dimensions.

The evolution of microcircuit fabrication has reached or almost reached two fundamental limitations. In size, the technology is rapidly approaching the limitations imposed by the wavelength of visible light. Five-micron circuit dimensions are used in routine production; masks for such circuits contain features only 10 wavelengths of light in size. In precision, the technology is rapidly approaching or possibly exceeding the dimensional stability of the silicon substrate. Precision mask alignments on the order of 1-micron accuracy are being used over 4-in. (10-cm) wafers, a precision of one part in 10^5.

The capital equipment required for further improvement in the technology is different in kind from that in use today. To overcome the size limitations imposed by the wavelength of light, an impressive collection of electron beam pattern-generation machines has been developed. These devices can make remarkably accurate and remarkably detailed patterns having features ranging down to the submicron level. To use these patterns efficiently, an array of pattern replication systems has been built by using X-rays, ultraviolet radiation, and electron imaging systems. These devices are very different from those used in current production.

Yet in spite of the need for entirely new production methods for circuits of finer dimensions, U.S. industry generally appears to persist in incremental development. Having removed the wavelength of light as a barrier to further minification, industry might be expected to push rapidly toward the 0.1-micron feature sizes predicted as the absolute minimum on the basis of solid-state theory. At present, however, there does not seem to be any effort to explore the physical limits of small size independent of device count (the number of components per circuit). Incremental improvement in feature size while maintaining or increasing device count is an appropriate route for industry to take, considering that industrial developments are driven by competitive economic forces and that too bold a technological step may prove economically fatal. But the knowledge gained by making devices with very small feature dimensions can be put to good use both in guiding our aspirations and in rationalizing our capital investments, while postponing, if necessary, the difficulties introduced by making complex circuits out of such devices.

The microcircuit industry is now at a turning point. New methods will be implemented to obtain smaller dimensions. New pattern generation and pattern replication equipment will be put into service. Basic choices presently being made will affect the entire industry for the next 20 years, and some of the relatively inexpensive research objectives undertaken now may have considerable future leverage. Not only will improvements in our national capability to produce microcircuits meet specific defense requirements for smaller, faster, and lower power circuits than are now available, they will also provide a better base for all defense electronics. This report outlines the fundamental principles that should guide the choice of such research topics.