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VLSI Technology

Fundamentals and Applications

Editor: Y. Tarui

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Preface

The origin of the development of integrated circuits up to VLSI is found in the invention of the transistor, which made it possible to achieve the action of a vacuum tube in a semiconducting solid. The structure of the transistor can be constructed by a manufacturing technique such as the introduction of a small amount of an impurity into a semiconductor and, in addition, most transistor characteristics can be improved by a reduction of dimensions. These are all important factors in the development. Actually, the microfabrication of the integrated circuit can be used for two purposes, namely to increase the integration density and to obtain an improved performance, e.g. a high speed. When one of these two aims is pursued, the result generally satisfies both.

We use the English translation "very large scale integration (VLSI)" for "Cho LSI" in Japanese. In the United States of America, however, similar technology is being developed under the name "very high speed integrated circuits (VHSI)". This also originated from the nature of the integrated circuit which satisfies both purposes. Fortunately, the Japanese word "Cho LSI" has a wider meaning than VLSI, so it can be used in a broader area.

However, VLSI has a larger industrial effect than VHSI. The reason lies in the economic effect of the reduction of the cost per unit function, resulting in rapid enlargement of the area of application and expansion of the scale of the industry; all these effects originate from the scale of the integration. Therefore, as industry proceeds to introduce, first, very large scale integration, improvement of performance, such as high speed, will accompany this.

This book contains the main results of research performed in the Cooperative Laboratories of the VLSI Technical Research Association, together with some additional, related technology. The Cooperative Laboratories were organized for the four years 1976-1979, with about 100 people being temporarily transferred from five computer manufacturers and the Electrotechnical Laboratory.

Technological Fundamental necessities and common interests have determined the selection of the research theme at the Cooperative Laboratories. Because of the principle of the selection and the limited period of 4 years, the development of the fabrication apparatus and technology was selected as the first important theme. The second important theme was the problem of the silicon crystal. In addition, fundamental and common interests on the part of the process technologies, test technologies and device technologies were selected. Thus, as the selection of the themes was made on the basis of fundamental and common interests, we expect this book will be interesting as fundamental knowledge for readers.

Finally I would like to express my sincere appreciation to people concerned in the Government, related companies, Universities, Japan Electronic Industry Development Association and the VLSI Technology Research Association headed by Mr. N. Nebashi, former executive director, for their guidance and cooperation which made this worthwhile research possible.

Tokyo, October 1985 *Yasuo Tarui*

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Contents

1. Introduction

Very Large Scale Integration (VLSI) is in technical concept within the widely expanded field of the semiconductor integrated circuits. The integrated circuit itself was invented in the process of microminiaturization of electronic circuits. In the early stage the purpose of microminiaturization was literally to make the electronic devices smaller and lighter, especially for use in missiles and satellites.

Microminiaturization started in the form of a high-density assembly with components being fabricated in small size and combined in condensed form. The assembling of complex circuits with discrete components of variable size soon reached a limit because handling of the components and, in particular, their wiring became complex like a spider's net.

This limitation led to the idea of the "module" structure. Such structures are characterized by an assembly of component units with standardized regularity and separation. In the module structure, however, it is still necessary to handle each component one by one. This was a limitation for further miniaturization and became economically unfeasible.

The breakthrough in the difficulty of handling each component was achieved by the concept of the integrated circuit for which components are fabricated together and handled together. The integrated circuit is defined as "the microstructure of many circuit elements inseparably associated on or within a continuous substrate". In other words, an integrated circuit is handled as a functional unit for the design, the fabrication and the test. Thus, the concept of circuit integration opened a new area of microminiaturization, but it suffered from the difficulty of handling each component separately.

1.1 The Significance of Semiconductor Integrated Circuits

When the semiconductor integrated circuits were entering production, continuously improved by technological advances, it became clear that the merits of

integration not only lead to the original aim of smaller and lighter devices, but to an increase of high reliability, low cost and high performance.

The main reason for those merits today is the dramatic escalation of the units of electronic devices from R (resistance), C (capacitance), L (inductance) and transistors to the functions of the systems. Instead of the assembly of components one by one, only a series of photographic processes determines the locations of several millions of components, or how several millions of wires are connected. In addition, as all components are put into monolithic form, many electrical connections and encapsulations are superfluous.

Thus, the merits of integrated circuits with respect to cost, reliability and performance are recognized as generally applicable to all electronic devices. To utilize them, integration became the guiding principle in the electronic industry.

The advantages of integration are becoming more evident as the number of components on a chip is increasing. For this reason, the number of integrated devices or the "integration level" on a chip is to be increased. This increase led to an overall economic optimum, including yield considerations.

1.2 Prospects of High-Density Integration

As mentioned above, the development from integrated circuits (IC) to large-scale integration (LSI) has been achieved in the last twenty years. A quantitative expression is given by the complexity of a chip. The annual change of this number of components on a chip is commonly used to represent that tendency. Figure 1.1 shows it for memory circuits; the number of components in-

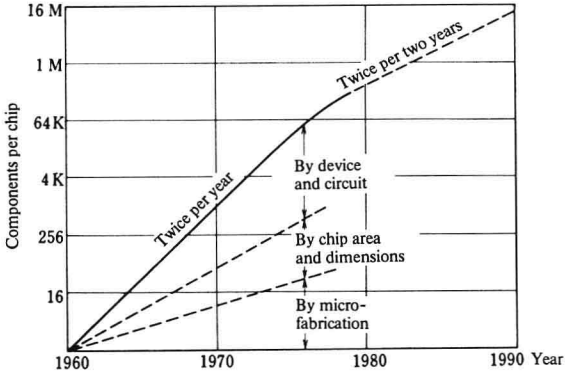

Fig.1.1. Illustrating the increase of the number of components per chip and the decomposition into different steps