

Integrated Circuit Fabrication



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Dr. Kumar Shubham

Associate Professor
Delhi Technical Campus
Greater Noida, Uttar Pradesh
India

Ankaj Gupta

Assistant Professor
Delhi Technical Campus
Greater Noida, Uttar Pradesh
India



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Preface

The book for students in engineering and technology curricula. It is a comprehensive treatment of integrated circuit fabrication. This text will be very useful to every student and practicing professional dealing with fabrication process. It covers theoretical and practical aspects of all major steps in the fabrication sequence. This book can be used conveniently in a semester length course on integrated circuit fabrication. This text can also serve as a reference for practicing engineer and scientist in the semiconductor industry.

IC Fabrications are ever demanding of technology in rapidly growing industry where growth opportunities are numerous. A recent survey shows that integrated circuit currently outnumbers humans in UK, USA, India and China. The spectacular advances in the development and application of integrated circuit technology have led to the emergence of microelectronic process engineering as an independent discipline.

Integrated circuit fabrication text books typically divide the fabrication sequence into a number of unit processes that are repeated to form the integrated circuit. Most students have difficulty recalling all of the background material. They have seen it once, two or three years and many final exams ago. The effect is to give the book a analysis flavor: a number of loosely related topics each with its own background material. It is vital that this fundamental material be re-established before students take up new material.

Manuscript Organization

Chapter 1 presents brief historical overview of major semiconductor devices and vital technological development, as well as introduction to basic fabrication step. Introduces crystal growth and process to obtain single crystal of silicon.

Chapter 2 deals with epitaxy. The purpose of epitaxy is to grow a silicon layer of uniform thickness and accurately controlled electrical properties and so to provide a perfect substrate for the subsequent device processing.

Chapter 3 presents silicon oxidation. It refers to the conversion of the silicon wafer to silicon oxide (SiO_2 or more generally SiO_x). The ability of Si to form an oxide layer is very important since this is one of the reasons for choosing Si over Ge.

Chapter 4 discuss lithography. It is the process of transferring patterns of geometric shapes in a mask to a thin layer of radiation-sensitive material (called resist) covering the surface of a semiconductor wafer.

Chapter 5 explain the process of etching that explain dry and wet etching process of different materials.

Chapter 6 refers diffusion to the entire process of adding a dopant to the surface of wafer at high temperature.

Chapter 7 discuss ion-implantation which replaces diffusion process in IC fabrication for reliable and reproducible doping.

Chapter 8 presents Film Deposition which contains two part Dielectric film deposition and metallization. It contains SiO_2 and Si_3N_4 film deposition which act as passivative material in IC. Metallization refers to the metal layers that electrically interconnect the various device structures fabricated on the silicon substrate. Thin-film aluminum is the most widely used material for metallization, and is said to be the third major ingredient for IC fabrication, with the other two being silicon and SiO_2 .

Chapter 9 deals with packaging. It is final stage of IC fabrication. In this the tiny block of semiconducting material is encapsulated in a supporting case that prevents physical damage and corrosion.

Chapter 10 is all about VLSI process integration. It presents fundamentals of integrating silicon processing steps to create silicon devices.

In this text over 400 references have been cited, of which 30 percent were published in last ten years, and over 200 technical illustrations are included, of which 45 percent are new. The problems at the end of each chapter form an integral part of the development of the topic. We have also attempted in each chapter to conclude some discussion of future trends. This book is organized somewhat differently than other texts on this general topic.

Suggestions for further improvements of the book will be gratefully acknowledge.

Authors

Introduction to Silicon Wafer Processing

1.1 INTRODUCTION

Designing a complex electronic machine of compact size like a laptop or mobile, it is always desired and necessary to increase the number of components involved in order to make technical advanced. The logic operation parts of the machines are conducted through integrated circuits made of semiconductor material. The monolithic integrated circuit placed the previously separated diodes, transistors, resistors, capacitors and all the connecting wiring onto a single crystal (or 'chip'). The monolithic integrated circuit was fated to be invented as two inventors who were unaware of each others activities, invented almost identical integrated circuits or ICs at nearly the same time.

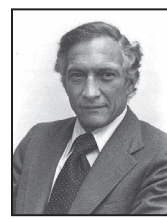
Jack Kilby, an engineer from Texas Instruments in 1958 with a background in ceramic-based silk screen circuit boards and transistor-based hearing aids had similar idea of making a whole circuit on a single chip as of research engineer Robert Noyce who had co-founded the Fairchild Semiconductor Corporation in 1957.

What we didn't realize then was the integrated circuit would reduce the cost of electronic functions by a factor of a million to one, nothing had ever done that for anything before" – Jack Kilby

In 1961 the first commercially available integrated circuits came from the Fairchild Semiconductor Corporation.



Jack Kilby



Robert Noyce

Fig. 1.1 Photo image of (a) Jack Kilby (b) Robert Noyce

Jack Kilby holds patents on more than sixty inventions and is also well known as the inventor of the portable calculator (1967), awarded the National Medal of Science in 1970. Robert Noyce, with sixteen patents to his name, founded Intel, the company responsible for the invention of the microprocessor, in 1968. The invention of the integrated circuit by both men stands historically as one of the most important innovations of mankind as almost all modern products use chip technology. Kilby used Germanium and Noyce used silicon for the semiconductor material.

All computers then started to be made using chips instead of assembling the individual transistors and their accompanying parts. Texas Instruments first used the chips in Air Force computers and the Minuteman Missile in 1962. They later used the chips to produce the first electronic portable calculators. The first IC had only one transistor, three resistors, and one capacitor having a size of an adult's pinkie finger. Today an IC smaller than a penny can hold more than 1 billion transistors.

The advantages of integrated circuits are as follows

1. Small in size due to the reduced device dimension
2. Low weight due to very small size
3. Low power requirement due to lower dimension and lower threshold power requirement
4. Low cost due to large-scale production and cheap material
5. High reliability due to the absence of a solder joint
6. Provide facilitation to integrate large number of devices and components.
7. Improves the device performance even at high-frequency region

The disadvantages of integrated circuits are as follows

1. IC resistors have a limited range
2. Due to bulky size generally inductors (L) cannot be formed using IC
3. Transformers cannot be formed using IC.

1.2 VLSI GENERATIONS

Historically, the first semiconductor IC chips held one transistor with three resistors and one capacitor. Advancement of technology enabled us to add more and more number of transistors.

The first to arrive was Small-Scale Integration (SSI), then improvements in technique led to devices with millions to billions of logic gates—Very Large-Scale Integration (VLSI).

Present day's microprocessors have millions of logic gates and transistors. Intel co-founder, Gordon E. Moore, in 1965 published a paper on the future projection of IC technology.

Moore's Law is responsible for "smaller, compact, cheaper and more efficient IC". Gordon Moore's empirical relationship is cited in a number of forms, but its essential thesis is that the numbers of transistors that can be manufactured on a single die will double every 18 months.

Wickes (1969) in his paper categorizes between SSI, MSI and LSI by the number of logic gates implemented on single chip where single equivalent logic gate is taken as the fundamental building block. On this basis a SSI circuit is one which has 1~10 equivalent logic gates, an MSI circuit is one which has 10~100 logic gates and LSI circuit is one which has more than 100 logic gates. (e.g., random access bipolar memory modules have approximately 500 equivalent gates and other advanced modules are expected to have four times the number.) After the success of LSI, the era of Very Large Scale Integration (VLSI), Extra Large Scale Integration (ELSI), Ultra Large Scale Integration (ULSI), etc has begun with having the ability to perform a very complex logic function, or a large number of simple logic functions in very short time.

The first generation integrated circuits contained only a few transistors called "Small-Scale Integration" (SSI), they used circuits containing transistors numbering in the tens.

SSI circuits were used in early Aerospace project and Missile projects. The two major program of that time, Minuteman missile and Apollo program needed lightweight digital computers for their inertial guidance systems. The Apollo guidance computer motivated the integrated-circuit technology, while the Minuteman missile forced it into mass-production which led SSI to become commercial. These programs acquired almost all of the available integrated circuits from 1960 through 1963, and almost alone provided the demand that funded the production improvements to get the production costs from \$1000/circuit (in 1960 dollars) to merely \$25/circuit (in 1963 dollars). After the successful implementation in defense industry they began to appear in consumer products a typical application being FM inter-carrier sound processing in television receivers.

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