Integrated circuits and fabrication

Motivation

So far we have discussed about the various devices that are the heartbeat of core electronics. This modules aims at giving an overview of how these solid state devices are actually compacted and commercialized in the form of integrated circuits (ICs).

In this module you get to learn how ICs, several resistors, capacitors and transistors are integrated and fabricated into this one bug-like structure. We present answers to queries like, what are the different scales and advantages of this integration? What is the Moore's law on integration levels? What are the well-known ways of fabrication of ICs?

Learning Objectives

In this module we aim to present a picture of how the solid state devices, presented in previous modules, are integrated and used on a large scale in industries and educational institutions.

1. Summarize the basic concepts, methods, difficulties and utilities of the renowned techniques behind IC fabrication.
2. The objective is also to give an analysis of the well-known Moore's Law.
3. Consequently one should be able to asses the exponential growth in the level of integration with time.

Prerequisite

Basic concept of all previous modules (transistors, diodes, etc.) and digital logic.

Suggested Reading time

3 hour

Suggested Exercise time

2 hour

Introduction

Integrated circuit (IC) is a set of electronic circuits on one small buglike plate ("chip") of semiconductor material, normally silicon. It can be made very smaller compared to a discrete circuit made from independent components. They play a major role in modern day electronics and are mostly made for specific tasks. They contain up to thousands of transistors, diodes and resistors. Special purpose IC's such as audio-amplifiers, FM radios, logic blocks, regulators and even a whole micro computers in the form of a micro controller can be fitted inside a tiny package. Based on the method of manufacturing the ICs can be divided majorly in two categories: hybrid and monolithic. Integrated circuits can be also divided into two further groups: analog (linear) and digital. The output voltage of an analog circuit is continuous, and follows changes in the input. For example, when a signal from a microphone is connected to the input the output will vary in the same way as the voltage from the microphone. Contrarily, in digital IC's, the output voltage is discrete. It is either LOW or HIGH and it changes from one state to the other very quickly. For example, in ICs designed to perform boolean logic operations like AND, OR, NOT etc.

Integrated Circuits

So far we have covered several devices like the p-n junction diode, BJT, FET and p-n-p-n switching devices. These devices (particularly transistors) are regarded as the basic building blocks of electronic circuits. Transistors can be used to make various logic gates (AND / OR / NOT), which in turn form digital circuits, subsystems and finally a large digital system. Similarly, transistors are used in analog designs like amplifiers, and hence form the basis of analog circuits too. Modern systems employ very complex digital and analog circuits, which means that the number of transistors that must be used are also very high (in the order of millions). Obviously, laboratory transistors even of the size of a grain can lead to very large electronic systems, increased area and power dissipation. The earliest computer which used vacuum tubes were of the size of a hall for the same reason. Hence, a need to bring down the size of circuit building components and their integration was raised.

With the advent of transistors, this problem got a novel solution. The transistors are smaller devices which retain their properties to very miniaturized scales of size. Hence a large number of them can be fabricated on a single silicon chip. FETs show more compaction and scalability than BJTs. The process of growing a large number of miniature transistors on a single silicon chip to realize a larger circuit or otherwise, is termed as **integration**. Integration technology has now revolutionized electronic industry and made it possible for computers once the size of a hall fit in our pockets, with advanced features and negligible power dissipation.

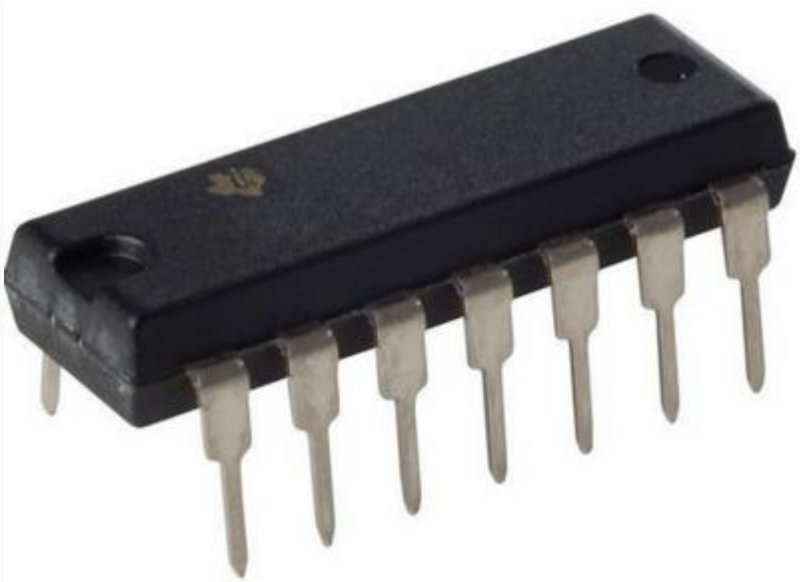

Figure 10.1 An IC

Image taken from www.diytrade.com

Given above is a figure of an Integrated circuit chip. Note that this is only an external view with the casing and connection pins. The actual integrated circuit is a very small sized one placed inside the protective casing, with its ports connected to aluminium pins for breadboarding.

Scales of Integration

The integration technology has advanced a lot since its advent. The various scales of integration that are possible in electronic circuits are as follows :

1). **SSI** : Small Scale Integration - Growing 10-50 transistors on a single chip.

2). **MSI** : Medium Scale Integration - Growing 100-1000 transistors on a single chip.

3). **LSI** : Large Scale Integration - Growing 1000-1,00,000 transistors on a single chip.

4). **VLSI**: Very Large Scale Integration - Growing over a billion transistors on a single chip.

Recent developments in technology have made it possible to fabricate even more gates on a single chip. **ULSI**, **WSI** and **3D IC** are examples of such technologies, which are beyond the scope of this course.

Moore's Law

As we noted, the number of transistors that can be accommodated on a single chip are increasing every year. But does a mathematical relation exist between the number of transistors and time? **Gordon Moore** studied IC fabrication trends and gave out a very famous law in the filed of semiconductor technology, known as**Moore's Law**. The law is a very simple one, which says that "the number of transistors that can be incorporated on a single chip doubles after every 18 months." A recent and more reliable version mentions this time period to be approximately two years. This shows the immense rise in the level of integration, and helps research facilities and industry set their goals.

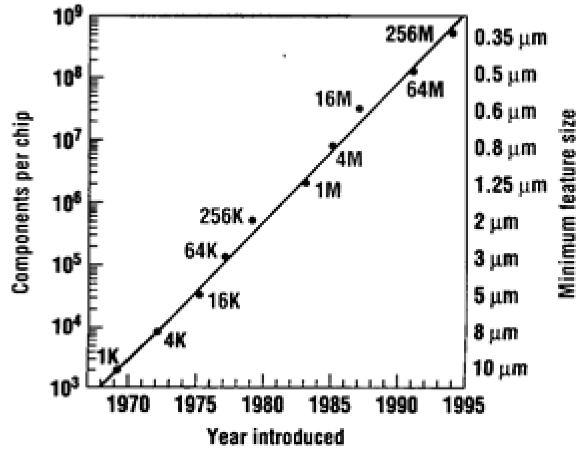

Figure 1.1 Memory and minimum feature sizes for dynamic random access memories as a function of time.

Image taken from http://njtechreviews.com/2011/09/04/moores-law/

IC fabrication technology

The fabrication of ICs is a technically elaborate process, which requires specialization, accuracy and investment. The cost of equipment and the technology required makes a single transistor very costly (in the order or a million!), but since transistors are always produced in millions of quantities on a single chip, the overall cost per transistor comes out to be very low. This is the major reason for a surge in the use of transistors in electronic circuits, side by side reducing the cost of electronic components (excluding organizational profits).

The 'Lambda' of IC Technology

Since the advent of IC fabrication technology, there has been immense growth and development in this field. As the size of transistors reduces with time, new technologies pop up in a period of a few years. Each technology is characterized by a number, known as its **feature size**. It is the minimum channel length that a transistor fabricated using that technology can have. Thus, a technology with feature size 180nm can have a channel as short as 180nm, and will be called as **180**

nm technology. The current trends followed are 65nm, 45 nm and 32 nm.

Another quantity associated with fabrication technology is *lambda*, which is usually half of feature size. It is the shortest measurement unit in a transistor. All the distances in a transistor (channel length, pitch, width of oxide etc) are measured in terms of multiples of *lambda*. Lengths below *lambda* are not measurable in an IC.

Fabrication Process

ICs are usually fabricated by growing p type, n type and metal regions insulated by silicon dioxide on a single silicon chip to make transistors, capacitors and resistors. The heart of whole IC fabrication is a process known as **photolithography** – which uses UV masking to make patters on the silicon wafer and then implant these patterns with impurities (p type or n type)/polysilicon/metal . The mask is usually made by patterning glass with chrome. This is carried out multiple times - depositing one quantity at a time to create a pattern of p, n and polysilicon areas which are connected by metal so as to make the required circuit. The basics steps involved in IC fabrication of a simple p-n-p transistor are as follows :

1). Grow a layer of Silicon Dioxide on n- type chip using oxidation.

2). Deposit a layer of *photoresist* on oxide.

3). Using a mask, expose the photoresist to UV radiation. The photoresist softens in the areas exposed to UV light.

4). Etch the softened photoresist and underlying oxide using acid. This exposes the area to be diffused with p+ impurities.

5). Develop the p+ source and drain regions using either gaseous implant or bombarding.

6). Remove the remaining photoresist and oxide layer with a stronger solution called ‘Piranha Etch’.

7). Repeat the above steps for polysilicon (gate) and metal contacts. The metal is deposited on exposed regions by a process called *sputtering*.

These steps will create a single p-n-p transistor on a chip. As stated above; the mask, UV emitter and other equipment are very expensive. However, the transistors are actually replicated and this brings down the production cost. The transistors /gates/ICs/SoCs are then cut, packaged (as in Single/Dual Inline package), tested and sold.

Memory

We can't imagine life without space to store our data. But where is this data stored? The answer is semiconductor memory, which is an electronic data storage device. A semiconductor-based integrated circuit is used to construct the memory in many different types and technologies. Let us have a quick look as to how is the system's memory constructed. Firstly, in a semiconductor memory chip, each bit of binary data is stored in a tiny circuit called a memory cell. This cell consists any number of transistors ranging from one to many. These memory cells are then laid out in rectangular arrays on the surface of the chip. Finally, the 1-bit memory cells are grouped in small units called words which are accessed together as a single memory address. But there is certain standard by which the memory is used. The word length for storage is usually a power of 2.

What are the functions that one can perform on memory? The two basic operations performed by a memory chip are 'read', and 'write'. In read, the data contents of a memory word is read out and in write the new data is written replacing any data that was previously stored there. These days, blocks of semiconductor memory are integral parts of many computer and data processing integrated circuits. For example the microprocessor chips that run computers contain cache memory to store instructions awaiting execution.

Famous types of memory are:

RAM: (Random access memory) This can be written to as well as read from.

SRAM: (Static random-access memory) This is less dense but expensive.

DRAM: (Dynamic random-access memory) This is slower that SRAM but cheap.

ROM: (Read-only memory) Is able to read only and not write.

PROM: (Programmable read-only memory) Data can be written only once.

EPROM: (Erasable programmable read-only memory) Data can be written to the chip. To erase the data one needs to use ultraviolet light.

EEPROM: (Electrically erasable programmable read-only memory) The writing process is slow. Data can be rewritten electrically. An important use is BIOS code.

FLASH: (Flash memory) It can be written to but is not fast enough so as to replace main memory.