Lecture 1

• Introduction to Semiconductor Processing.
• A Brief History of Integrated Circuits.
Introduction to Semiconductor Processing

Semiconductor Processing

• This course is about the process by which we can make electronics from sand:

• The success of semiconductor technology has undoubtedly been one of humankind's greatest achievements.
• We are incredibly lucky that the silicon has the properties it does, and is the 2nd most abundant element in earth's crust.
• In 2021 transistors can be purchased at a cost of $10^{-7}$ USD / transistor when part of integrated circuit.
Why do you Care:

• Highly applicable knowledge for jobs in the semiconductor industry.
• The process you will follow is similar to the basic process followed by semiconductor fabrication facilities (e.g. Intel).
• The point of a course like this is to ensure you are able to go into an interview and talk with confidence on the subject.
• Information may also be useful / necessary for many aspects of your research.
• It is also an interesting subject (hopefully).

What is a Transistor?

• We will learn more about transistors in Week 5 (Lectures 13 and 14), but briefly:
• A transistor is 3-Terminal Electronic switch.

• These are devices used to control flow of current between two terminals via a third terminal.
• The most important component of an integrated circuit is the transistor.
Water Analogy

- Consider an analogy of water flowing in pipes.
Water Analogy

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Water Analogy

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![Water Analogy Diagram]

Electrical Behavior

- A transistor can be considered to behave in a similar way:

![Electrical Behavior Diagram]
Electrical Behavior

- A transistor can be considered to behave in a similar way:

\[
\begin{align*}
\text{Drain Voltage} & \quad \text{Ammeter} \\
\text{Gate Voltage} & \quad \text{Source-Drain Current} \\
\text{Gate Voltage} & \quad \text{Drain Current}
\end{align*}
\]
Electrical Behavior

- A transistor can be considered to behave in a similar way:

Electrical Behavior

- Real transistors do not show this ideal behavior in reality:
Conventional Electronics

• Before we talk about thin-film electronics, let us talk briefly about conventional electronics.
• Conventionally we use transistors to **process** information.

![Diagram of a transistor with input (V_{in}) and output (V_{out})](image)

Electronic Circuits

• Originally circuits were designed on a printed circuit board, with copper wires connecting components.

![Image of an old computer](image)
Logic Circuits

• Connecting multiple logic components together we are able to create complex circuits:

• This is a simple arithmetic logic unit (ALU):

A Brief History of Integrated Circuits
1928: Transistor Patented

- Patent submitted in 1928 by Julius Edgar Lilienfeld.[1]

- Broadly similar to the metal-oxide-semiconductor field-effect transistors used today.


1947: The First Transistor

- Germanium was used in first transistor.
  - Demonstrated by Bardeen Brattain Shockley in 1947.[1]
  - Working at Bell labs, NJ.

1958: First Integrated Circuit

- The first “integrated circuit” was developed in 1958.\(^{[1]}\)
- Jack Kilby, Texas Instruments.
- Multiple circuit elements on same piece of Germanium.
- This circuit was not monolithic.
- This circuit elements were isolated by cutting groves into the chip and connected with gold wires.

\(^{[1]}\) [Source](https://patents.google.com/patent/US3138743A/en)

1960: First Monolithic IC

- The first monolithic planar integrated circuit was demonstrated in 1960.
- By Robert Noyce at Fairchild Semiconductor.
- He used silicon rather than germanium.
- Since the intrinsic carrier concentration in silicon is so low \(n_i \sim 10^{10} \text{ cm}^{-3}\), isolated regions can be formed that are highly resistive.
- \(p\) and \(n\)-regions could be formed by doping.
- It turns out that the native oxide silicon oxide is easy to grown and highly insulating.
MOSFETs

- Up to this point most IC’s were based on bipolar junction transistors (BJT’s). It was difficult to create a single chip with many (100’s) of transistors on it. The yield was very poor.
- Some at RCA (Radio Corporation of America) thought it would be possible to develop larger circuits from MOSFETs – based on the original Lilienfeld patent.

![Bipolar Junction Transistor vs. Field-Effect Transistor (FET)]

1965: First Stable MOSFETs

- Unfortunately silicon-based MOSFETs remained unstable and highly unpredictable.
  - I.e. for a certain set of applied voltages, different currents were measured in different devices, and at different times.
  - This was due to the quality of the SiO₂ and Si surface states.
  - Individuals at RCA (Frederic Heiman, Steven Hofstein) and Andy Grove (Fairchild) eventually discovered that inclusion of sodium and hydrogen can overcome these issues.
  - RCA demonstrated working MOSFET circuits in 1965.
  - Andy Grove along with George Moore founded Intel in 1968.
Integrated Circuits

• During the 1960’s and 1970’s more and more MOSFETs were combined into integrated circuits.

Integrated Circuits

• Original circuit design was painstaking and limited complexity.
Modern IC Development

• Nowadays the process is incredibly sophisticated.

Sand to Ingot

Wafer Dicing

https://www.youtube.com/watch?v=d95WkLZvA8g

Photolithography

Ion Implantation

https://www.youtube.com/watch?v=d95WkLZvA8g
Modern IC Development

- Nowadays the process is incredibly sophisticated.

**Etching**

**Deposition**

https://www.youtube.com/watch?v=d9SWNLZvA8g

Modern IC Development

- Nowadays the process is incredibly sophisticated.

**Electrodeposition**

**CMP**

https://www.youtube.com/watch?v=d9SWNLZvA8g
Modern IC Development

- Nowadays the process is incredibly sophisticated.

Circuit Design

Packaging

https://www.youtube.com/watch?v=d9SWNLZvA8g

Intel’s D1X Hillsboro Fab

https://www.youtube.com/watch?v=Qo2ydLURSkg
Moore's Law

- Suggested in the 1960’s by Intel’s founder Gordon Moore.
- The number of transistors that can inexpensively fit onto a single integrated circuit will double every 24 months.\[1\]
- Today transistors can be purchased at a cost of $10^{-7}$ USD / transistor when part of integrated circuit.


Moore’s Law

- Remarkably, it has held up for 40 years.

Microprocessor Transistor Counts 1971-2011 & Moore's Law
Moore’s Law

- This has been driven by reducing feature size:

![Interconnects](image1.png)

80 nm minimum pitch

52 nm (0.65x) minimum pitch

52 nm Interconnect Pitch Provides Better-than-normal Interconnect Scaling

Global Semiconductor Sales

![Global Semiconductor Sales](image2.png)

Summary

• We have introduced the subject of semiconductor processing, and why it is important.

Next Time...

• After the break we will cover the course content and the course logistics.