Introduction to Electronic Devices

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Introduction to Electronic Devices

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Ref.: Apple

Ref.: IBM

Critical dimension (m)

Ref.: Palo Alto Research Center
Introduction to Electronic Device

1 Introduction

1.1 Motivation
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References
1 Introduction

1.1 Motivation

Pass on the extensive knowledge on electronic devices, semiconductor materials, and their application to integrated circuits.

Pass on sense of history of one of mankind’s greatest inventions and its incredible technological journey.

Provide students with the skills needed in industry, academia: Electronics, circuit design, material science, nanotechnology.
1 Introduction

1.1 Motivation

Gross word production (GWP) and sales volume of electronics, automotive, semiconductors and steel industries from 1980 to 2000 and projected to 2010 [Ref.: M.S. Sze].
1.2 A little bit of history
1.2.1 The bipolar transistor

First transistor (Point-contact transistor using germanium). The transistor was invented by Bardeen, Brattain and Shockely at Bell Labs in 1947 [Ref.: M.S. Sze].

Schematic diagram of a point-contact transistor. [Ref.: Bardeen, Noble laudate lecture, 1956].
1.2.2 The metal oxide field effect transistor (MOSFET)

Photo of the first metal oxide semiconductor field effect transistor (MOSFET). The transistor was realized in 1960 [Ref.: M.S. Sze].

Schematic cross section of a metal oxide semiconductor field effect transistor (MOSFET).
1.2.3 Integrated Circuits

Integrated Circuits (1958)
Phase Shift Oscillator
Jack Kilby, Texas Instruments,

Planar Process (1962)
RTL (Resistor-Transistor Logic)
(Noyce and Hoerni)
1.2.3 Integrated Circuits

Operational Amplifier (1965)
Fairchild μA 709

Microprocessor (today)
Fairchild Clipper 100
1.2.3 Integrated Circuits

First microprocessor Intel 4004,
Manufactured in 1971
Size: 3 x 4 mm
2300 transistors
Clock: 108kHz

First microprocessor Intel 4004,
zoomed in
1.2.4 Overview of Inventions in the field of electronics

<table>
<thead>
<tr>
<th>Year</th>
<th>Semiconductor Device</th>
<th>Author(s)/Inventor(s)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1874</td>
<td>Metal-semiconductor contact</td>
<td>Braun</td>
<td>5</td>
</tr>
<tr>
<td>1907</td>
<td>Light emitting diode</td>
<td>Round</td>
<td>6</td>
</tr>
<tr>
<td>1947</td>
<td>Bipolar transistor</td>
<td>Bardeen, Brattain, and Shockley</td>
<td>7</td>
</tr>
<tr>
<td>1949</td>
<td>$p-n$ junction</td>
<td>Shockley</td>
<td>8</td>
</tr>
<tr>
<td>1952</td>
<td>Thyristor</td>
<td>Ebers</td>
<td>9</td>
</tr>
<tr>
<td>1954</td>
<td>Solar cell</td>
<td>Chapin, Fuller, and Pearson</td>
<td>10</td>
</tr>
<tr>
<td>1957</td>
<td>Heterojunction bipolar transistor</td>
<td>Kroemer</td>
<td>11</td>
</tr>
<tr>
<td>1958</td>
<td>Tunnel diode</td>
<td>Esaki</td>
<td>12</td>
</tr>
<tr>
<td>1960</td>
<td>MOSFET</td>
<td>Kahng and Atalla</td>
<td>13</td>
</tr>
<tr>
<td>1962</td>
<td>Laser</td>
<td>Hall et al</td>
<td>15</td>
</tr>
<tr>
<td>1963</td>
<td>Heterostructure laser</td>
<td>Kroemer, Alferov and Kazarinov</td>
<td>16,17</td>
</tr>
<tr>
<td>1963</td>
<td>Transferred-electron diode</td>
<td>Gunn</td>
<td>18</td>
</tr>
<tr>
<td>1965</td>
<td>IMPATT diode</td>
<td>Johnston, DeLoach, and Cohen</td>
<td>19</td>
</tr>
</tbody>
</table>

Overview of the most important inventions in the field of electronics.

Ref.: M.S. Sze, Semiconductor Devices
1.2.4 Overview of Inventions in the field of electronics

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<thead>
<tr>
<th>Year</th>
<th>Semiconductor Device</th>
<th>Author(s)/Inventor(s)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>MESFET</td>
<td>Mead</td>
<td>20</td>
</tr>
<tr>
<td>1967</td>
<td>Nonvolatile semiconductor memory</td>
<td>Kahng and Sze</td>
<td>21</td>
</tr>
<tr>
<td>1970</td>
<td>Charge-coupled device</td>
<td>Boyle and Smith</td>
<td>23</td>
</tr>
<tr>
<td>1974</td>
<td>Resonant tunneling diode&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Chang, Esaki, and Tsu</td>
<td>24</td>
</tr>
<tr>
<td>1980</td>
<td>MODFET</td>
<td>Mimura et al.</td>
<td>25</td>
</tr>
<tr>
<td>1994</td>
<td>Room-temperature single-electron memory cell</td>
<td>Yano et al.</td>
<td>22</td>
</tr>
<tr>
<td>2001</td>
<td>20 nm MOSFET</td>
<td>Chau</td>
<td>14</td>
</tr>
</tbody>
</table>

Overview of the most important inventions in the field of electronics.

Ref.: M.S. Sze, Semiconductor Devices
1.3 Basic Electronic Device Building Blocks

Several ways exist to classify electronic devices. The most fundamental classification divides electronic devices in its basic building blocks. Four of these building blocks exist:

- metal semiconductor interface,
- pn junction,
- heterojunction and
- metal oxide semiconductor structures.
1.3 Basic Electronic Device Building Blocks

Basic electronic building blocks. All electronic devices can be derived from these basic building blocks.

(a) metal semiconductor interface, (b) pn-junction, (c) heterojunction interface, (d) metal oxide semiconductor structure.

Ref.: M.S. Sze, Semiconductor Devices
1.3 Basic Electronic Device Building Blocks

All electronic devices, like bipolar transistors, solar cells, MOS field effect transistors, can be derived from these basic building blocks. In almost all cases a real electronic device consists of several of these building blocks.

Example 1:
A real pn diode consists of a pn junction and two metal semiconductor interfaces.

Example 2:
A real metal oxide semiconductor field effect transistor (MOSFET) consists of a metal oxide semiconductor structure, two pn junctions and 3 metal semiconductor interfaces.
1.4 Electronic Materials

More than 95% of the electronic devices are based on silicon (Si) technology. Therefore, silicon is the most important material in semiconductor industry. Most of the electronic products like microprocessors or memory products are based on silicon technology. Alternative materials like gallium arsenide or germanium are used for specific applications, like light emitting diodes or ultra high speed electronics.

Nowadays the most important electronic device is the Metal oxide semiconductor field effect transistor (MOSFET). The MOSFET is closely related to Digital Electronics. If it comes to the realization of digital electronics the MOS transistor is the electronic device of choice. Bipolar transistors are mainly used in the area of analog electronics. Throughout the last 20 years we have seen a trend from analog to digital electronics. However, there is still (and will be) a need for analog electronics.
1.4 Electronic Materials

Market share of different electronic devices.

Interestingly the first transistors and the first integrated circuits were bipolar devices. Initially MOS technology had only an incremental advantage over bipolar technology. III-V technology (including materials like gallium arsenide) is of main interest in the area of optoelectronic devices like light emitting diodes.
1.5 The silicon roadmap

Exponential increase of the memory size (dynamic random access memory, DRAM) and microprocessor power over time. The curves are known as „Moore’s law“.

Ref.: M.S. Sze, Semiconductor Devices
1.5 The silicon roadmap

Growth curves for different technology drivers.

Ref.: M.S. Sze, Semiconductor Devices
1.6 What’s next? (Predictions and Outlooks)

What is beyond CMOS (Complementary metal oxide semiconductor) and MOSFET (metal oxide semiconductor field effect transistors)!

Devices are getting smaller and smaller. Will electronic devices reach quantum or even atomic dimensions?

What principles will they operate on?
1.6.1 Silicon electronics

What is beyond CMOS (Complementary metal oxide semiconductor) and MOSFET (metal oxide semiconductor field effect transistors)?

Gate oxide thickness of metal oxide semiconductor field effect transistors.

In 1997, a gate oxide was 25 silicon atoms thick.

In 2012, a gate oxide will be five silicon atoms thick.
1.6.2 Nanotechnology

Increasing the control over material structures of nanoscale size 0.1nm to 100nm.

**Top-down Approach towards Nanotechnology:**
Fabrication and realization of electronic devices from macroscopic down to nanoscopic scale by a step-by-step improvement of existing technologies: e.g. lithography in microelectronics.

**Bottom-up Approach towards Nanotechnology:**
Bottom-up refers to synthesis from individual molecules or atoms

The following mechanisms are used to build device structures:
- Surface tension, strain, hydrophilic/hydrophobic
- Selective growth
- Supramolecular chemistry
- Fluidic self-assembly
1.6.2 Nanotechnology

Carbon Nanotubes

Carbon Nanotube Inter- and Intramolecular Logic Gates. Ref.: V. Derycke et al, IBM Research Division,
1.6.2 Nanotechnology

Molecular and Organic Electronics

- **Carrier Mobility**
  - Crystalline silicon
  - Poly silicon
  - Nanocrystalline silicon
  - Amorphous silicon
  - Small molecules
  - Polymers

- **CMOS technology**
  - CPU, memory products

- **Low Cost ICs, drivers LCD displays**

- **Displays, smart cards**

- **Radio frequency identification tags**

- **E paper, E ink**

- **cm²/Vs**
References


