Electronic Functional Materials and Devices

电子功能材料与元器件

QQ Group:

陈晓龙 Chen, Xiaolong

电子与电气工程系

Who am I?

个人简介-陈晓龙

2018.09 – 现　　在: 南科大，助理教授，电子与电气工程系

2016.08 – 2018.08: 耶鲁大学，博士后，电气工程系

2015.04 – 2016.06: 剑桥大学，博士后，电气工程系

2010.09 – 2015.03: 香港科技大学，博士&博士后

2006.09 – 2010.06: 中国科学技术大学（少年班），本科

研究领域：新型二维中红外半导体与器件领域

My official website: http://faculty.sustech.edu.cn/chenxl/

My personal website: https://site-982068-1338-8517.mysxl.cn/

个人主页

「2D Material Lab」

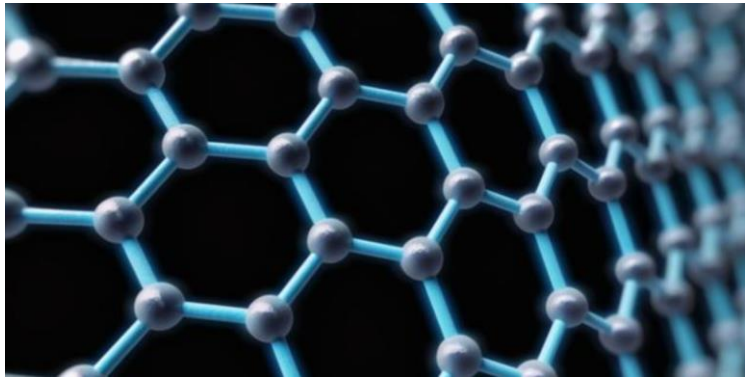
2D Materials: a **Bridge** that Connects Physics and Devices

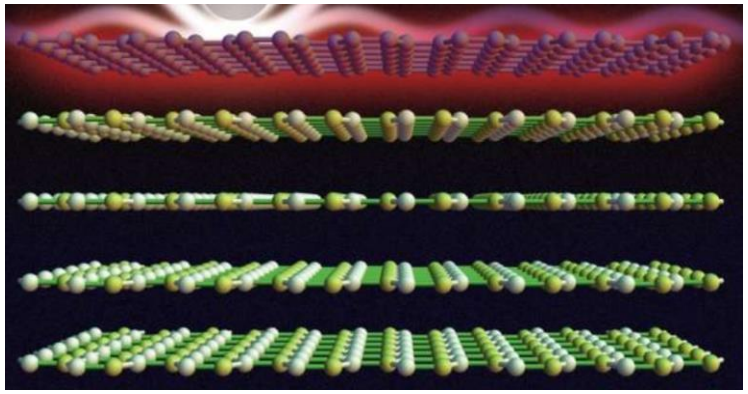
@Southern University of Science and Technology (Sustech), Shenzhen, China 南方科技大学

Research area

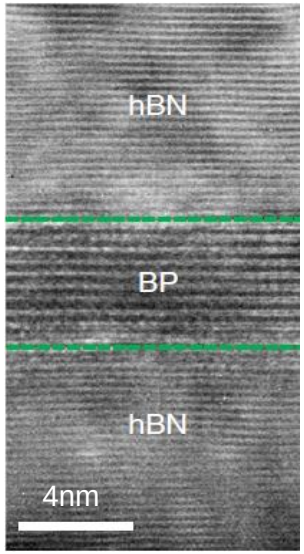
Physical properties, opto-electronic devices (especially mid-infrared) based on emerging two-dimensional semiconductors

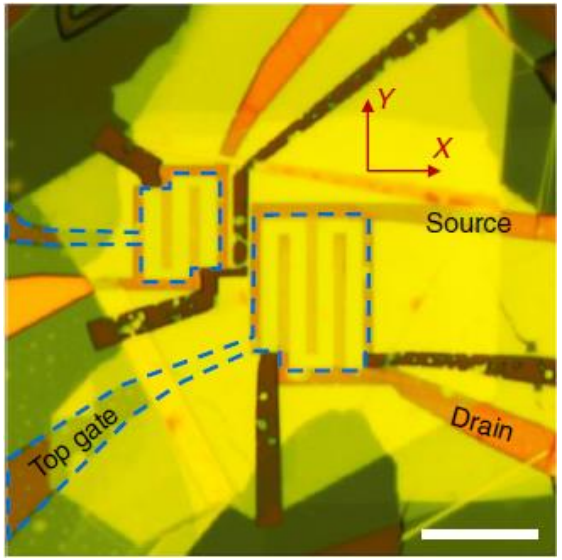
新型二维半导体物性、光电器件





- **Atomically-thin thickness**
- **“Lego” heterostructure**





Course Information

Presenter: Chen, Xiaolong

Office: Rm:223, Engineering Building

E-mail: chenxl@sustech.edu.cn

Class: Tue. (1-16), 19:00-20:50

Rm.106,3rd Teaching Building

Tur. (1,3,…,15), 19:00-20:50

Rm.106,3rd Teaching Building

Teaching Assistant:

Liang, Zihan 梁子寒
E-mail: 12231067@mail.sustech.edu.cn

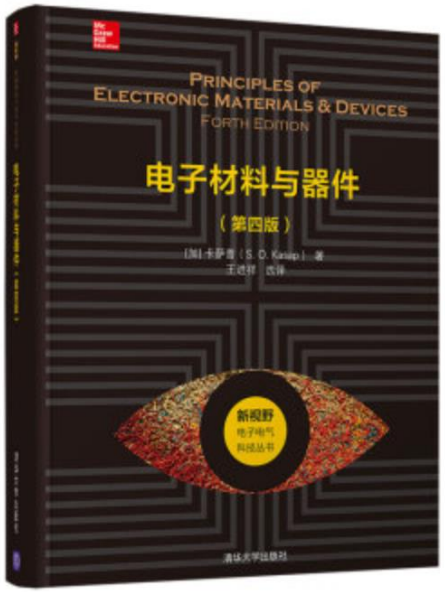
Chen, Shouheng 陈守恒
E-mail: 12232133@mail.sustech.edu.cn

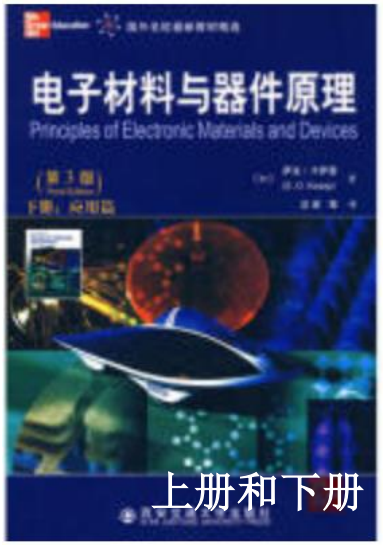
Wang, Han 王晗
E-mail: 12331216@mail.sustech.edu.cn

Shou, Tao 首涛
E-mail: 12232483@mail.sustech.edu.cn

QQ Group:

群名称:电子功能材料与器件
群　号:940368648

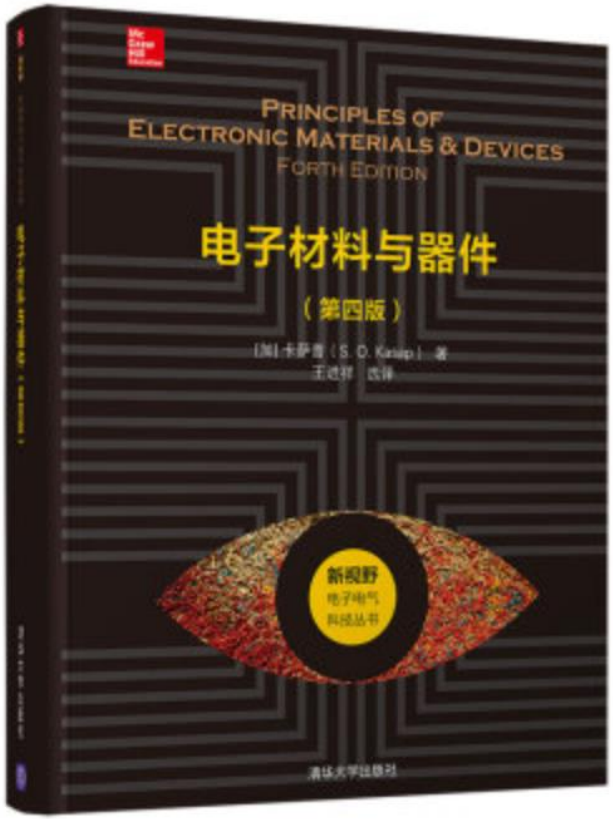


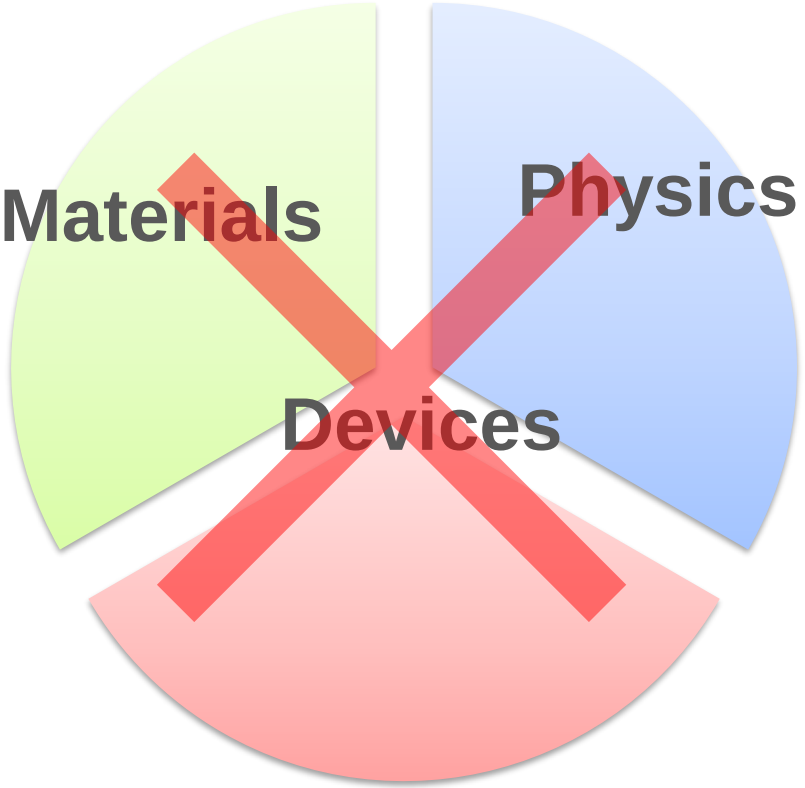


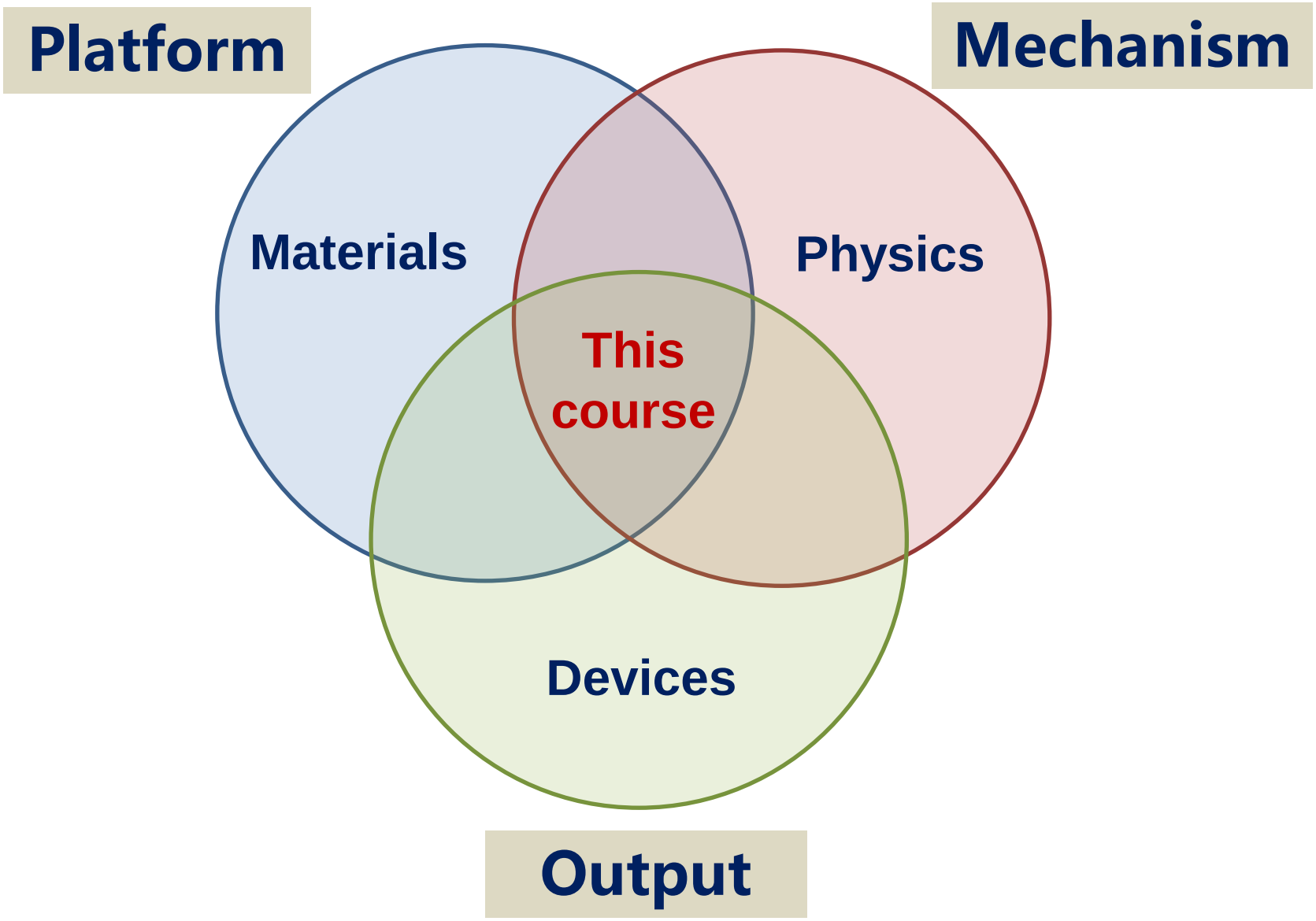
上册和下册

0. Introduction

This course covers a broad knowledge of materials, physics and devices





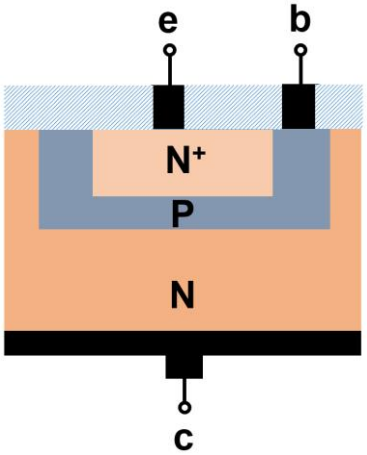

Platform
Mechanism
Materials
Physics
This course
Devices
Output

One example: the development of transistors

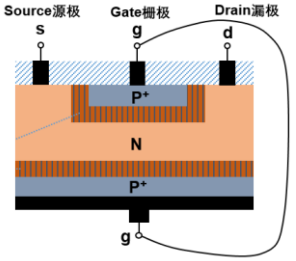
1904,
Vacuum tube

Heated cathode emit electrons

1947,
Transistor (BJT)



1950,
Junction field-effect transistors (JFET)



New device design

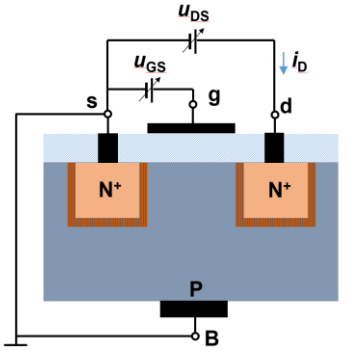
Physics: field effect

Material: Silicon, Germanium

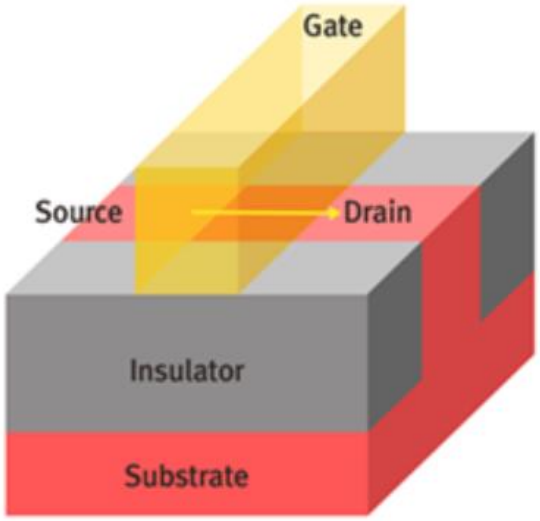
Device: N^+PN. P^+NP

Physics: PN junction

1959,
Metal-oxide-semiconductor FET (MOSFET)

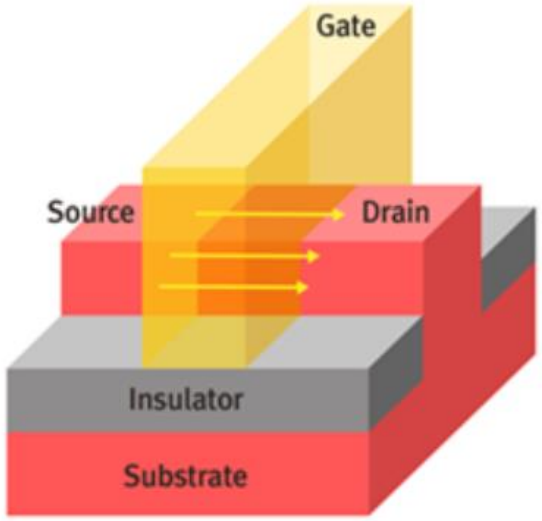


Planar structure

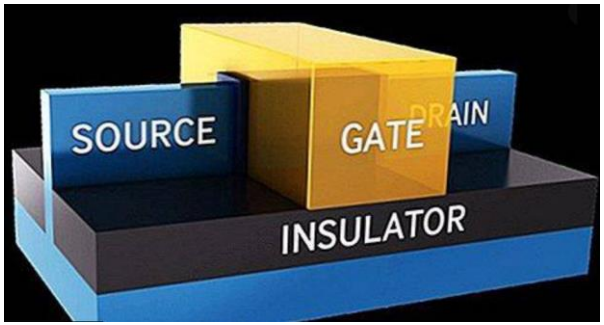


Traditional MOSFET

3D structure



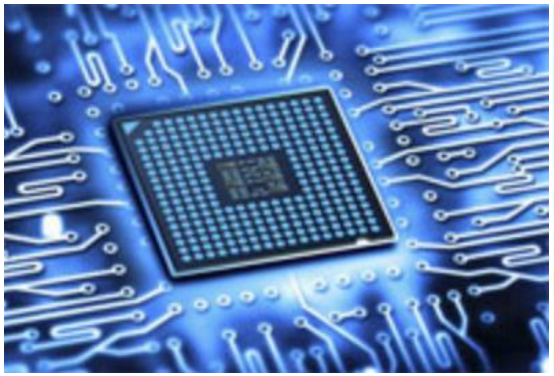
FINFET鳍式场效晶体管



Silicon is the king of the modern electronic world!

Some applications of silicon family (Si, SiO_2) in our real life:

Chip 芯片



Solar Cell

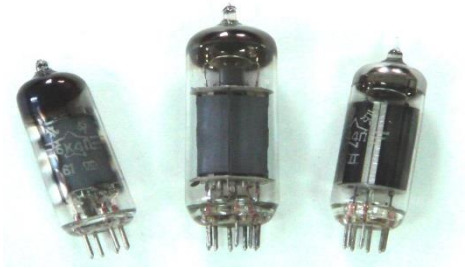
Optical Fiber 光纤

21th Century: Electronic and Information World

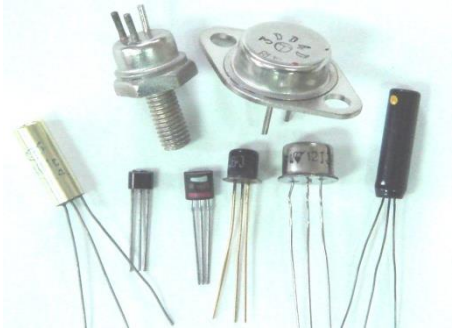
Electronics changes our world and life in every aspects.

The evolution of human

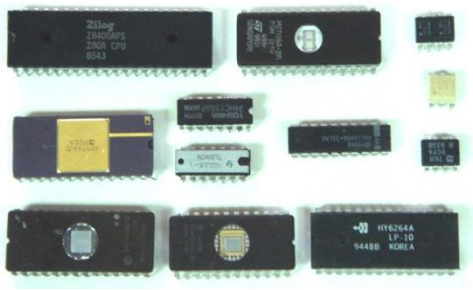
Development of electronic device



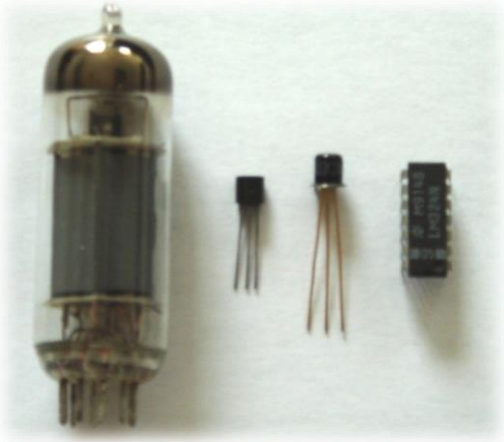
1904,
Electronic tube电子管



1947,
Transistor晶体管



1959,
Integrated circuit集成电路



Comparison of electronic tube, transistor, integrated circuit

Vacuum tube

1st generation electronic device 第一代电子器件

Electronic (vacuum) tube 电子管（真空管）

a. Vacuum shield

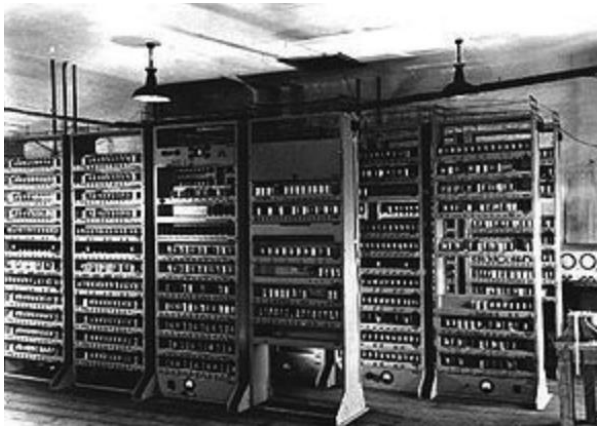
b. Cathode 阴极

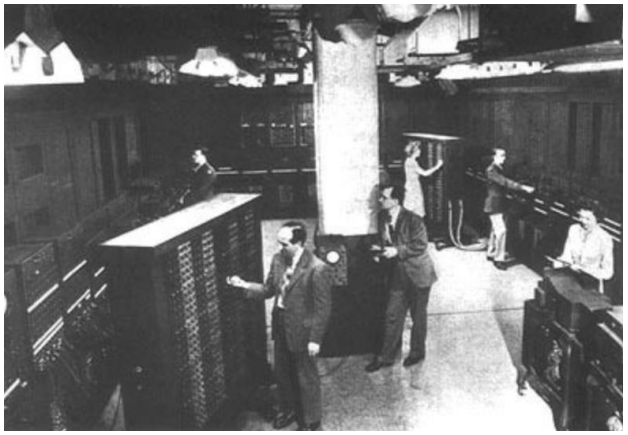
c. Heated cathode will emit electrons

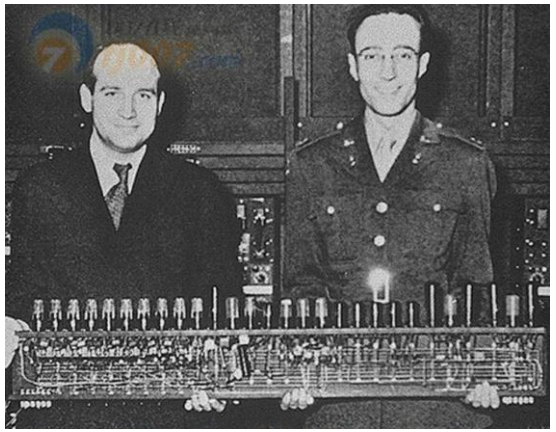
d. Current: Electrons motion under the electric field and magnetic field

Vacuum tube

1st computer is made of vacuum tube







The **ENIAC** was invented by **J. Presper Eckert** and **John Mauchly** at the University of Pennsylvania and began construction in **1943** and was not completed until **1946**.

Length: 50 feet; Width: 30 feet; Area: 1500 feet^2; Weight: 30 ton; Power consumption: 170 kW; 18000 vacuum tubes; Every 15min, one vacuum tube breaks; 据传每 ENIAC 每次一开机，整个费城西区的电灯都为之黯然失色。

In one second, it processes 5000 times plus/minus calculation or 500 times multiplication calculation.

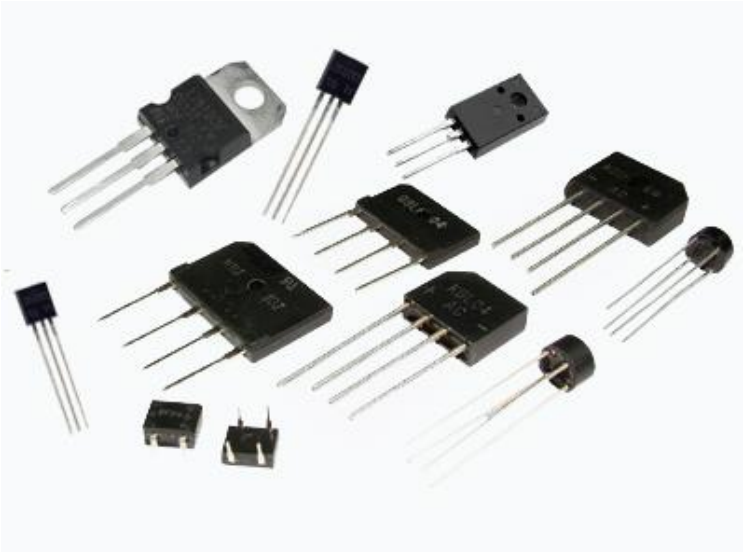
The disadvantage of vacuum tube:

- Big
- Heavy
- Power consumption
- Short lifespan

Transistor

2nd generation electronic device-- transistor 晶体管

1947, Bell Lab



Transistor is made of **semiconductors(半导体)**

John Bardeen (1908-1991), Walter House Brattain(1902-1987), and William Shockley (1910-1989)

John Bardeen

约翰·巴丁(John Bardeen)

He won Nobel Physics Prize twice

- 1956 for inventing transistors (Bardeen, Shockley, Brattain)
- 1972 for the BCS superconducting theory (Bardeen, Cooper, Schrieffer)

巴丁与珍妮

- **Born in 1908.05.28**
- **Went to University of Wisconsin at 15 years old**

  Majoring in Electrical Engineering

- **Went to Princeton University**

  Study Solid Physics

  Get married!

- **Join Bell lab in 1945**

  Work with Shockley and Brattain

  Aim at developing next-generation transistor (Shockley is the team leader)

- **Shockley proposed the metal-semiconductor junction structure**

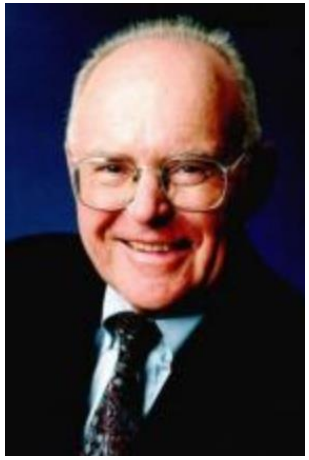
  No current rectification effect are observed

- **Bardeen proposed the surface states in semiconductors**

The first transistor in the world

Shockley was not listed in the inventor list

Noyce



Moore

- **Shockley invented junction FET secretly**
  - Kick out Bardeen and Brattain from Bell lab
  - Left Bell lab in 1955
- **Shockley opened his own lab in Silicon Valley in 1956**
  - Attract many young scholars:
  - Robert Norton Noyce, left in 1957
  - Gordon Moore, left in 1957
- **Noyce, Moore, et al. founded Fairchild semiconductor in 1957**
- **Noyce and Moore left Fairchild and founded Intel**

- 9 years after the invention of transistor, Bardeen, Shockley and Brattain **1956 won Nobel Physics Prize**.

有天晚上，一班物理学家和夫人自发组织拿着手电筒当火炬高歌祝贺巴丁，巴丁赶紧制止他们，“你们轻一点，别吵到我太太睡觉。”巴丁的“妻管严”（“henpecked”)是出了名的，连报纸的头版头条都是：“本地一女子的丈夫获得诺贝尔奖”。无论实验室工作有多忙，家里饭菜都是巴丁一个人包揽。

- In 1957, Bardeen, Cooper and Schrieffer proposed the BCS superconducting theory.
- In 1972 Bardeen, Cooper, and Schrieffer won **Nobel Physics Prize** for the BCS superconducting theory.

“Bardeen Number 巴丁数”

约翰·巴丁(John Bardeen)

The only person ever to win two Nobel Prizes in physics, John Bardeen’s name is barely known outside of the physics community.

Bardeen Number: the ratio of a physicist’s substance to his self-advertisement.

Transistor

Advantages:

a. Small & light

b. Long lifespan

c. Low power consumption

Disadvantages:

c. Sensitive to temperature

d. Poor overload capacity

Electronic circuit 电子电路

An electronic circuit is constructed through connecting electronic devices with resistors, inductors, capacitors, switches etc. to realize certain functions.

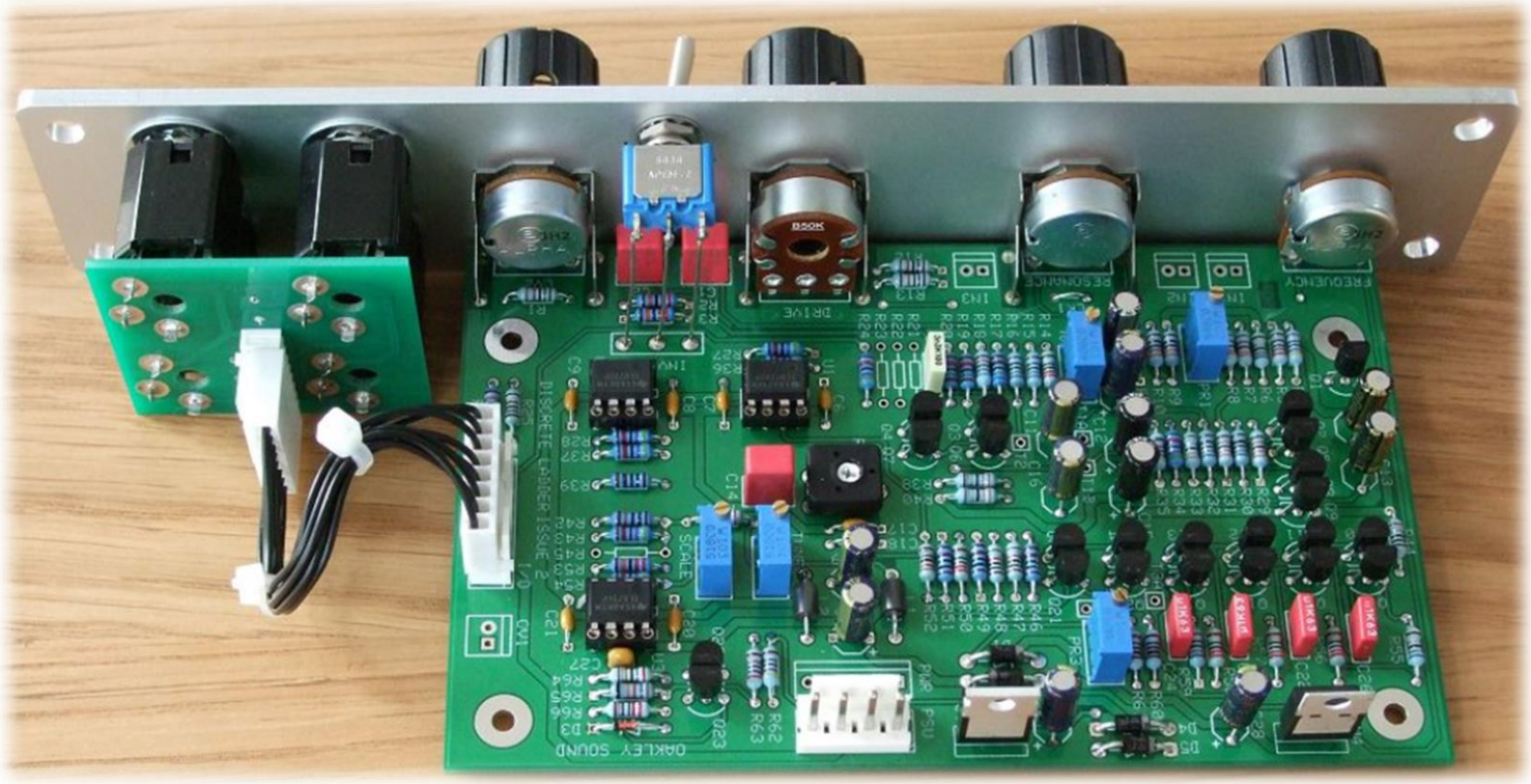
电子器件与电阻器、电感器、电容器、变压器、开关等元件适当地连接起来所组成的具有特定功能的电路。

Electronic circuit

- Discrete circuit 分立电路
- Integrated circuit 集成电路

Discrete circuit

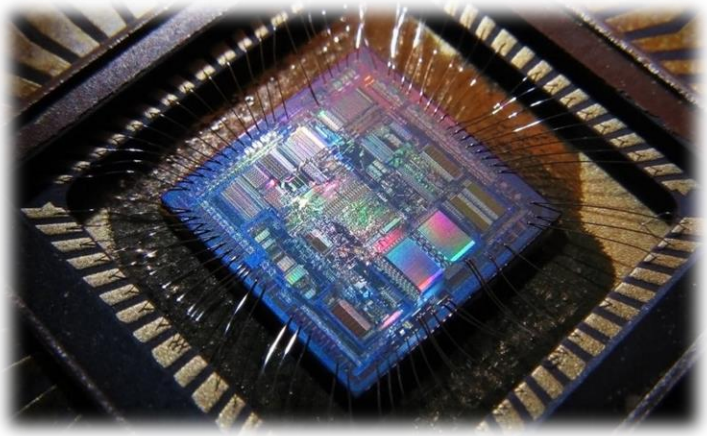
The electronic devices, resistors, capacitors and inductors are welded to the circuit board 把许多元件和器件焊接在印刷电路板上组成的



Large size，High power consumption，Low reliability

Integrated circuit-- IC

Integration of electronic devices (transistors) and components (resistors) on a single silicon chip



Advantages:

a. Small & light

b. Low power consumption

c. Liability

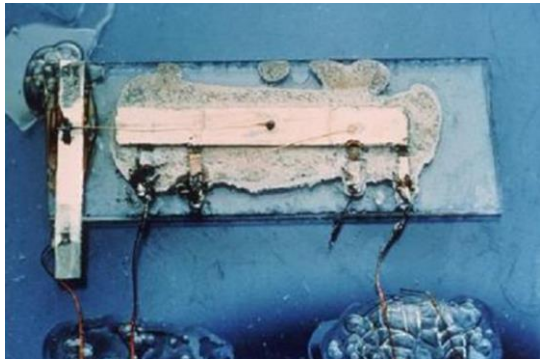
d. Long lifespan

Development of integrated circuit

The first IC is invented by **Jacky Kilby** in Texas Instruments in 1959

Only 4 transistors on germanium slab

Nobel prize in Physics, 2000



7/16 x 1/16 inch

(1) Small scale integration , SSI 小规模集成电路

Integration level: several tens of devices per chip

集成度：一块芯片上集成有几十个元器件。

Development of integrated circuit

(2) Medium scale integration , MSI 中规模集成电路

Integration level: several hundreds of devices per chip

(3) Large scale integration , LSI 大规模集成电路

Integration level: several thousands/tens-of-thousands of devices per chip

(3) Very large scale integration , VLSI 超大规模集成电路

Integration level: > several hundreds of thousands of devices per chip

Development of integrated circuit

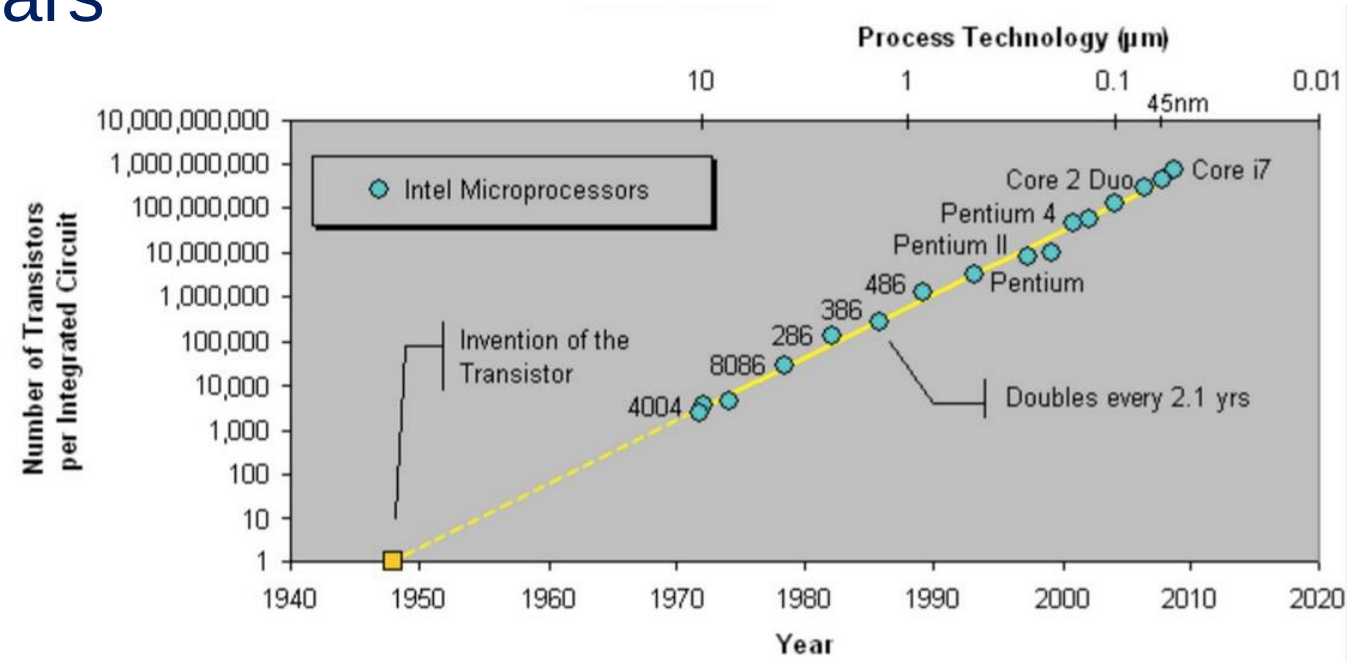
(5) State-of-the-art of IC

a. Over one hundred million devices per silicon chip

b. High speed and low power consumption

Development of integrated circuit

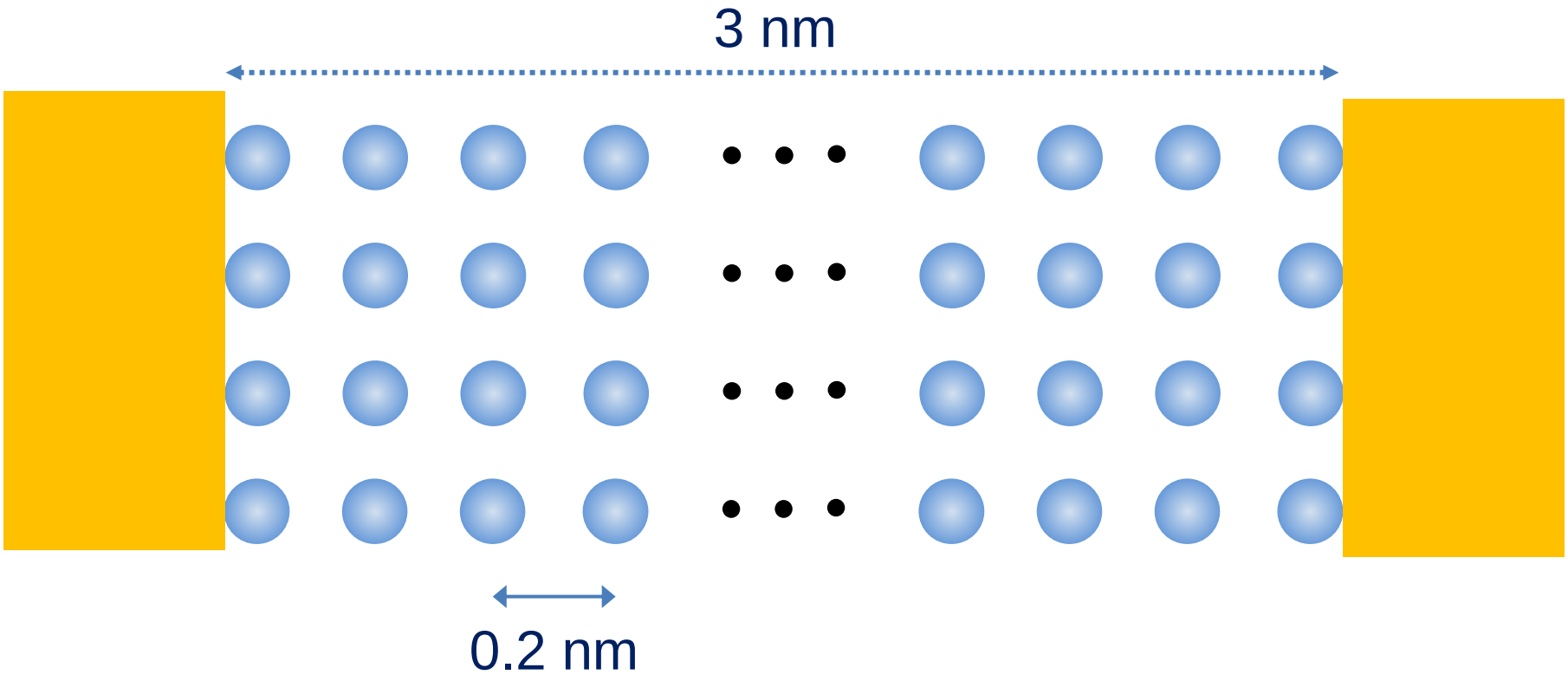
Moore's law: number of transistors per IC doubles every two years



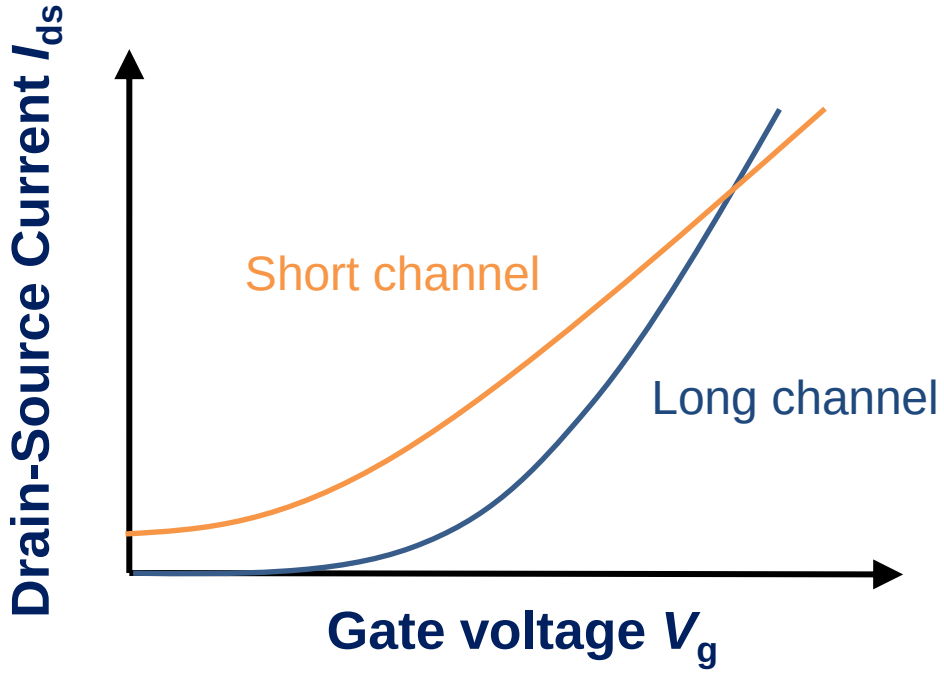
Development is slower after 2013

State-of-the-art transistor length is ~ 3 nm: only several tens of atoms

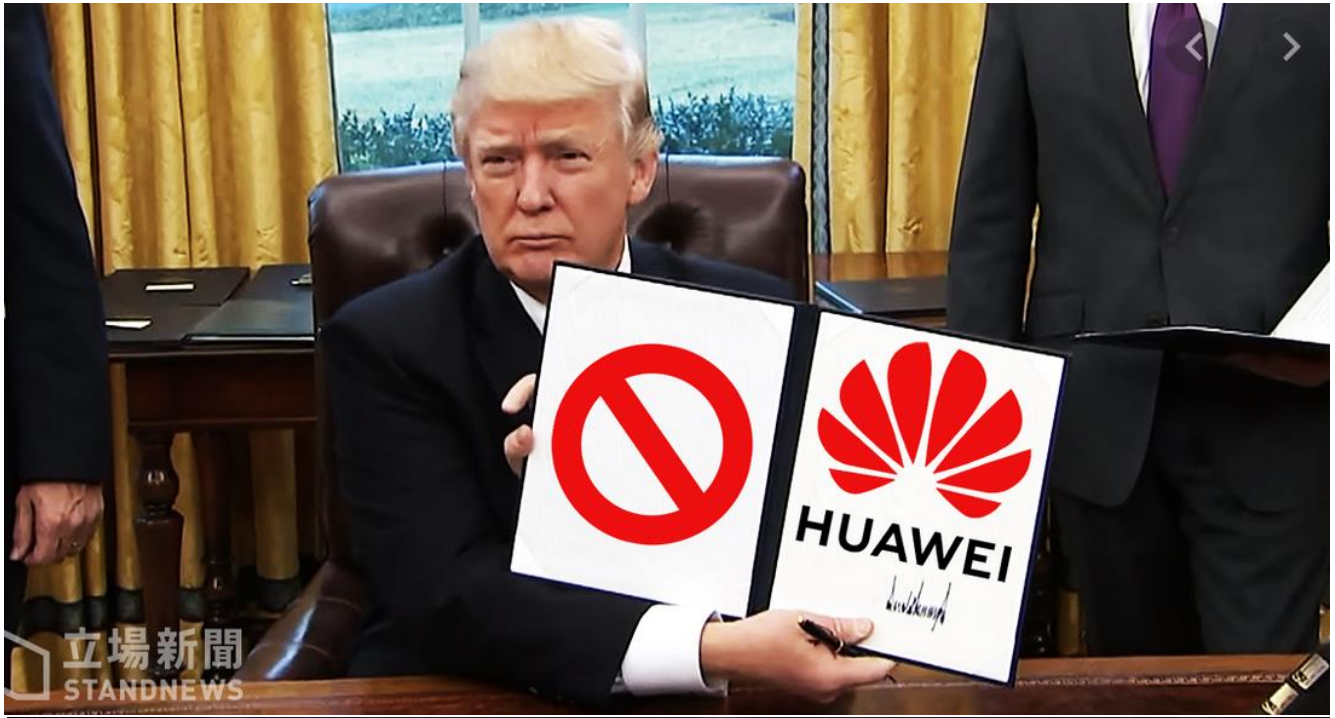
Short-channel device

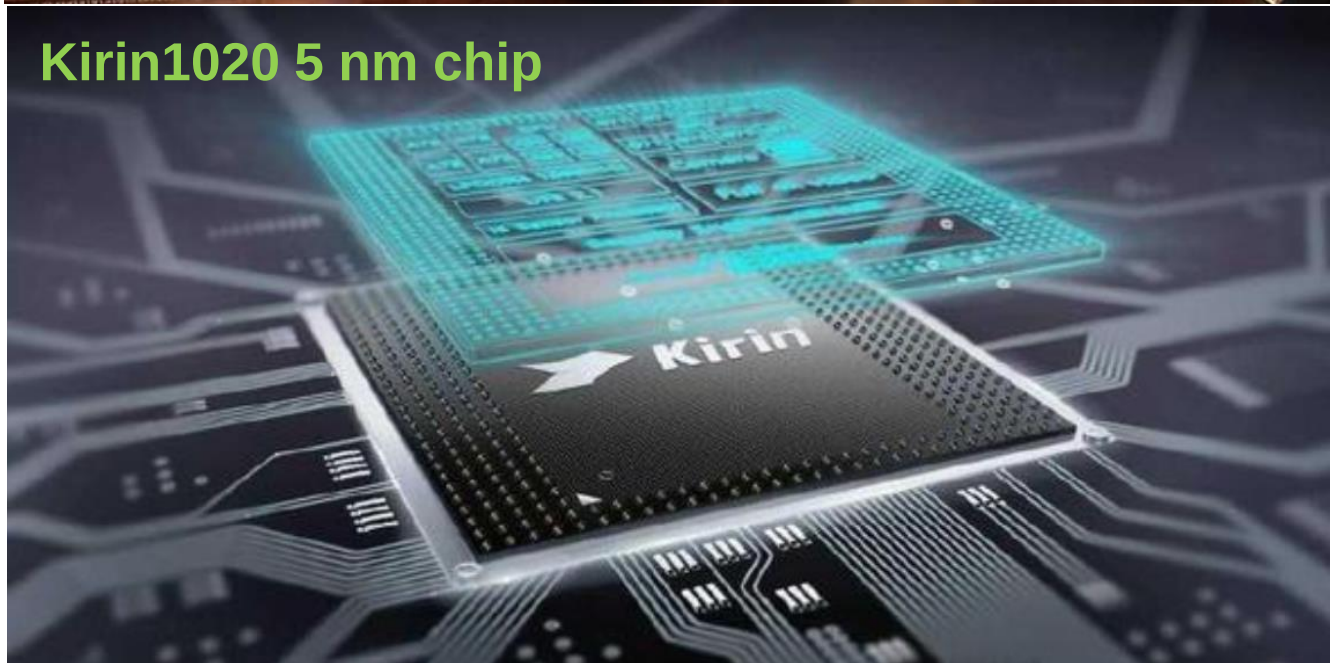


The effective channel length ≈ length of 15 atoms



Short-channel effect: the current in off-region increase dramatically, and power consumption increase


HUAWEI
立場新聞
STANDNEWS


Kirin1020 5 nm chip
Kirin

GPU and EDA …

What's the future of electronics ?

Novel electronic **materials**

Novel **physical mechanisms**

Novel **devices**

The content of this course

1. Fundamentals of materials (Material: Atom and crystal structure)

2. Electronic and thermal transport in solids (Classical Physics)

3. Modern theory of solids (Quantum Physics and Band Theory, Flash memory, laser)

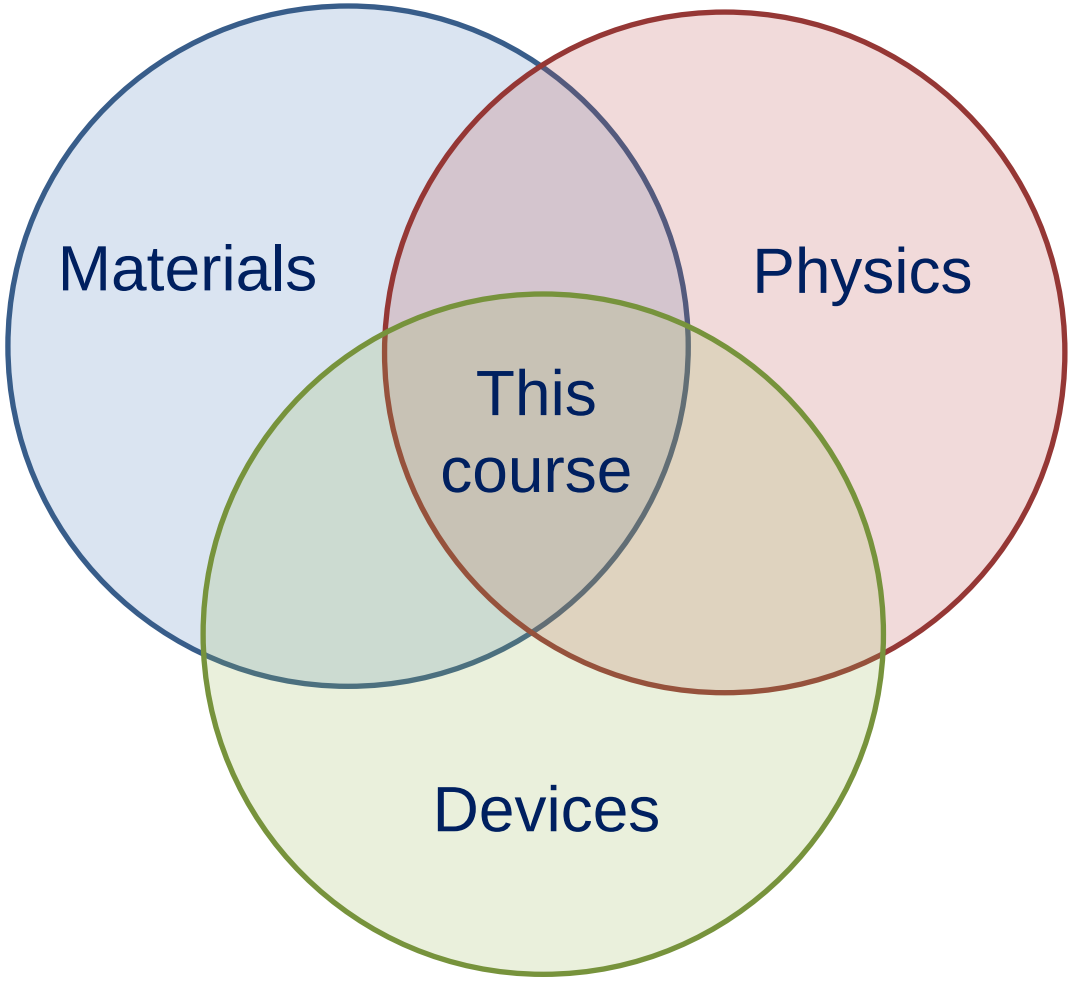
4. Semiconductors (Materials and Physics)

5. Semiconductor devices (PN junction, diode, BJT transistor, basic amplifier circuit, MOSFET, LED, photodetector, solar cell)

6. Dielectric material and devices (Capacitor, Touchscreen, Piezoelectric device, Crystal oscillator, Pyroelectric device)

7. Magnetic material and devices (Hard disc, Magnetic levitation)

The content of this course



My expectation to you：

- Understand the material properties.
- **Understand the physical mechanisms**.
- **Understand the device working principles**.
- **Able to design device with certain function**.

Course Evaluation 考核方式

Class attendance and participation，8-13%

上课人数少于70%，触发点名，未上课者扣一分，最多扣2分。

课堂提问回答有奖励分数，*答错不扣分，答对1分，3分封顶*。

Homework，20%

一次作业（主要练习画器件能带结构图和原理分析）。

Final exam 开卷考试（100分），70%

重视新型器件和原理的考察。

40%：应试题（选择、填空，问答等），课件有答案；

60%：发挥题（原理分析、器件设计等），课件无答案；

The Difficulty of this course

物理、微电、光电、材料等半导体相关良好背景 ★★★☆☆

接触过一些半导体知识 ★★★★☆

“老师，半导体是啥？” ★★★★★

乘风破浪会有时

多挂几科又何妨