

5G Technology and AI Applications

K. N. Tu

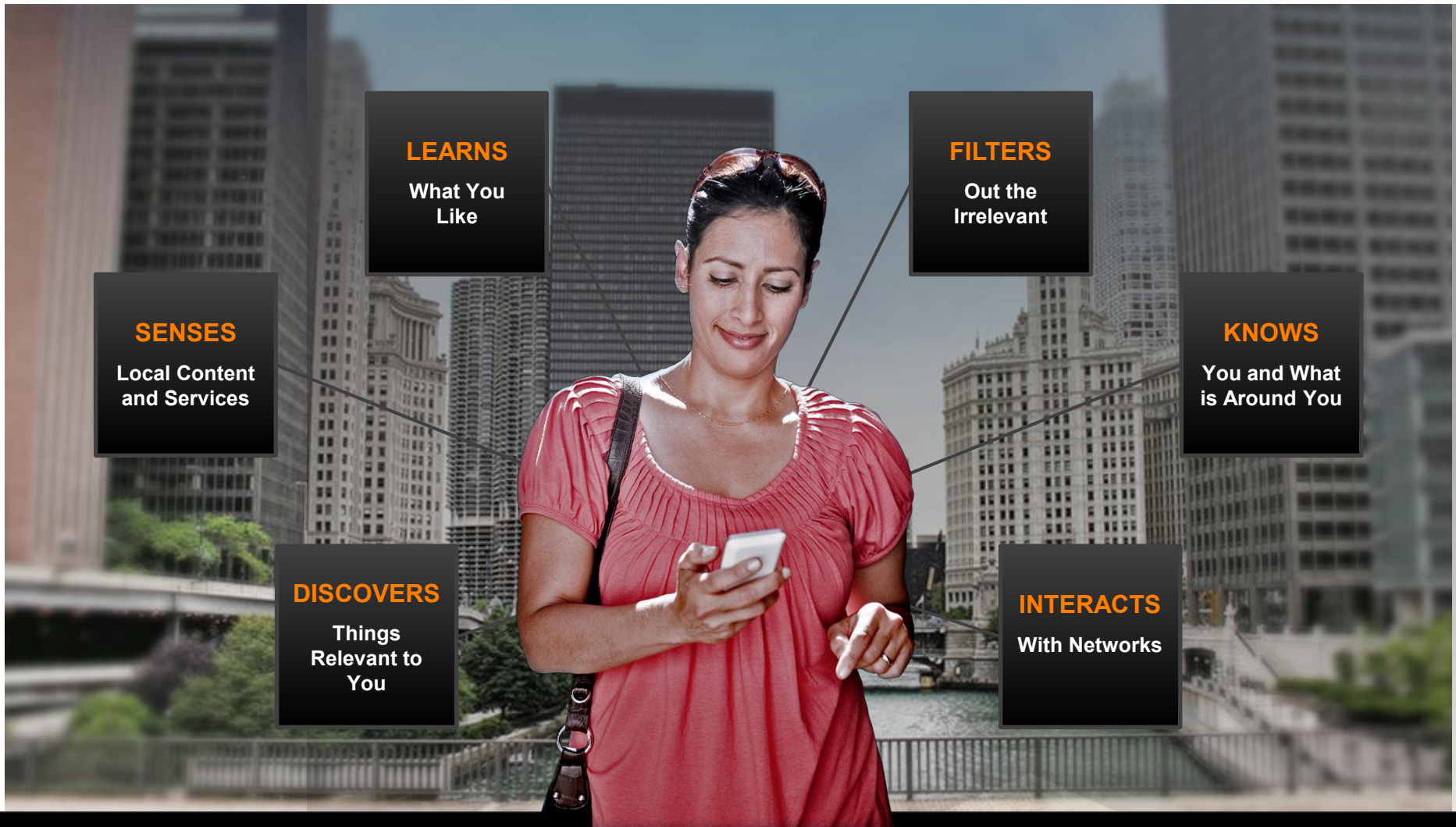
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1. Introduction
2. What is 5G and its technical standards?
3. What is AI and its applications?
4. An example of AI to improve reliability of 3D IC devices
5. Summary

City U, HK, Oct. 9, 2019

Recent events in semiconductor technology

- Japan has lost its leadership!
- Big European countries, England, France, and Russia have no presence in semiconductor technology.
- Taiwan and Korea now have the leadership!
- China wants to catch up. (I heard that it may take 10 years; why so long?)
- US and China trade war is about advanced semiconductor technology.
- Moore's law on miniaturization in Si transistor is ending.
- 5G and AI are here.

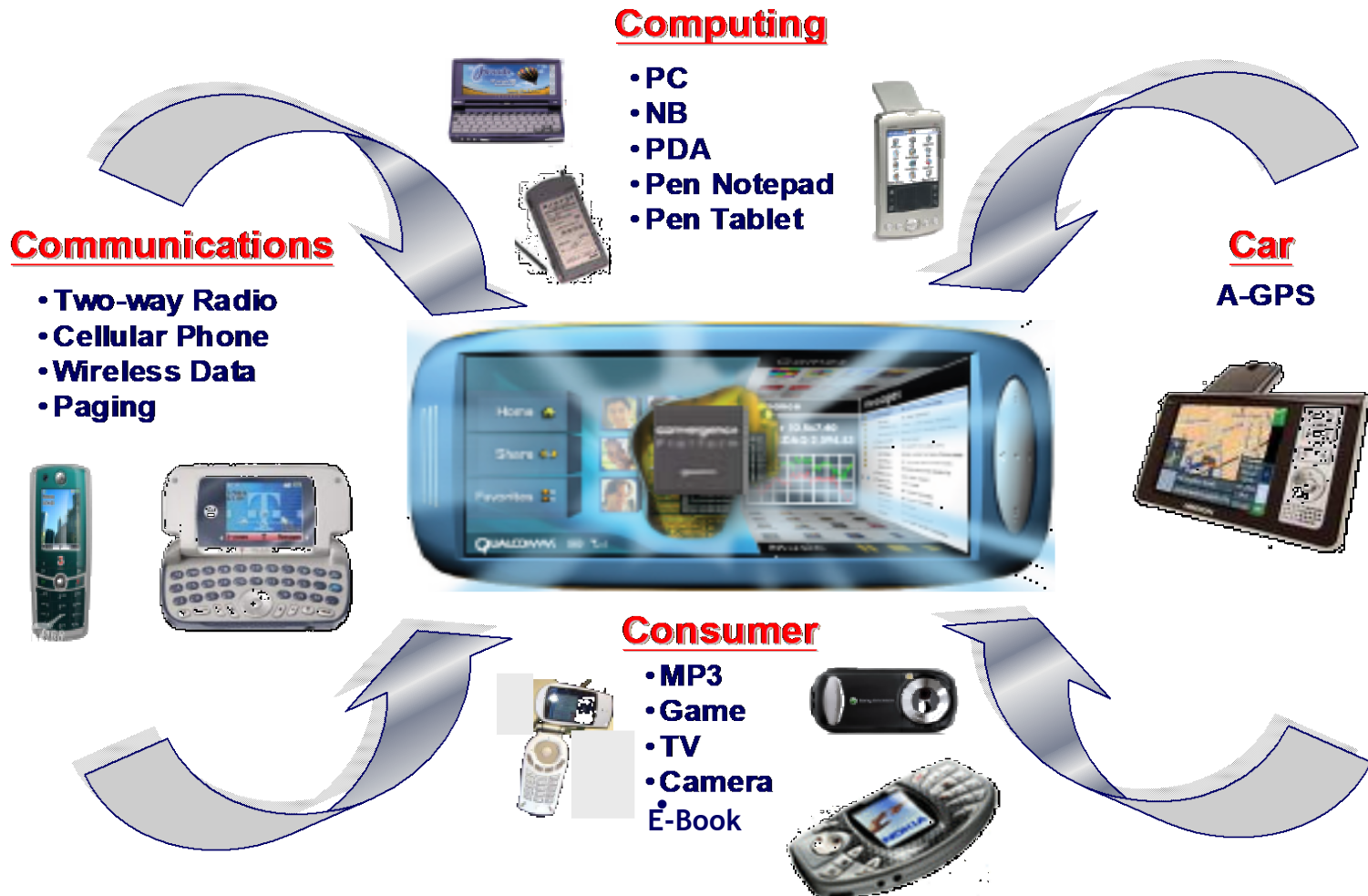


The Remote Control For Your Life (千里眼+順風耳)

IN THE FUTURE YOUR MOBILE PHONE WILL ACT AS YOUR DIGITAL “6TH SENSE”

Consumer Mobile Devices

We carry a “mobile computer”, rather than a phone!
5G + AI are changing our society rapidly!



Sources: Abdi (QCT) & Dataquest

Civilization Advancements

- The invention of **steam engine** led to **industrial revolution**. Machine power replaces animal power. Industrial production led to capitalism, communism, and socialism!
- The invention of **transistor and very-large-scale-integration (VLSI)** of transistors led to **intelligence revolution**. Data power enhances machine power; robots can do work for us. Our society is changing rapidly!

Sustainability; Two major trends

- **1st trend is to sustain energy consumption and environmental protection; we need new green energy technologies, and waste management.**
- **2nd trend is Moore's law, which has sustained the growth of microelectronic products for over 40 years. Now, Apple and Amazon both have market value over US\$1 trillion! How to sustain the future growth?**

Progress in Communication 通訊之進步

1. Language, 語言
2. Written words, 文字
3. Printing, Bible, and books, 印刷
4. Telephone, wire and wireless, 電話與電報
5. Television, 電視
6. Internet, (computer-to-computer) 互聯網
7. Mobile internet, (cell phone-to-cell phone)
移動互聯網

dot.com (burst)

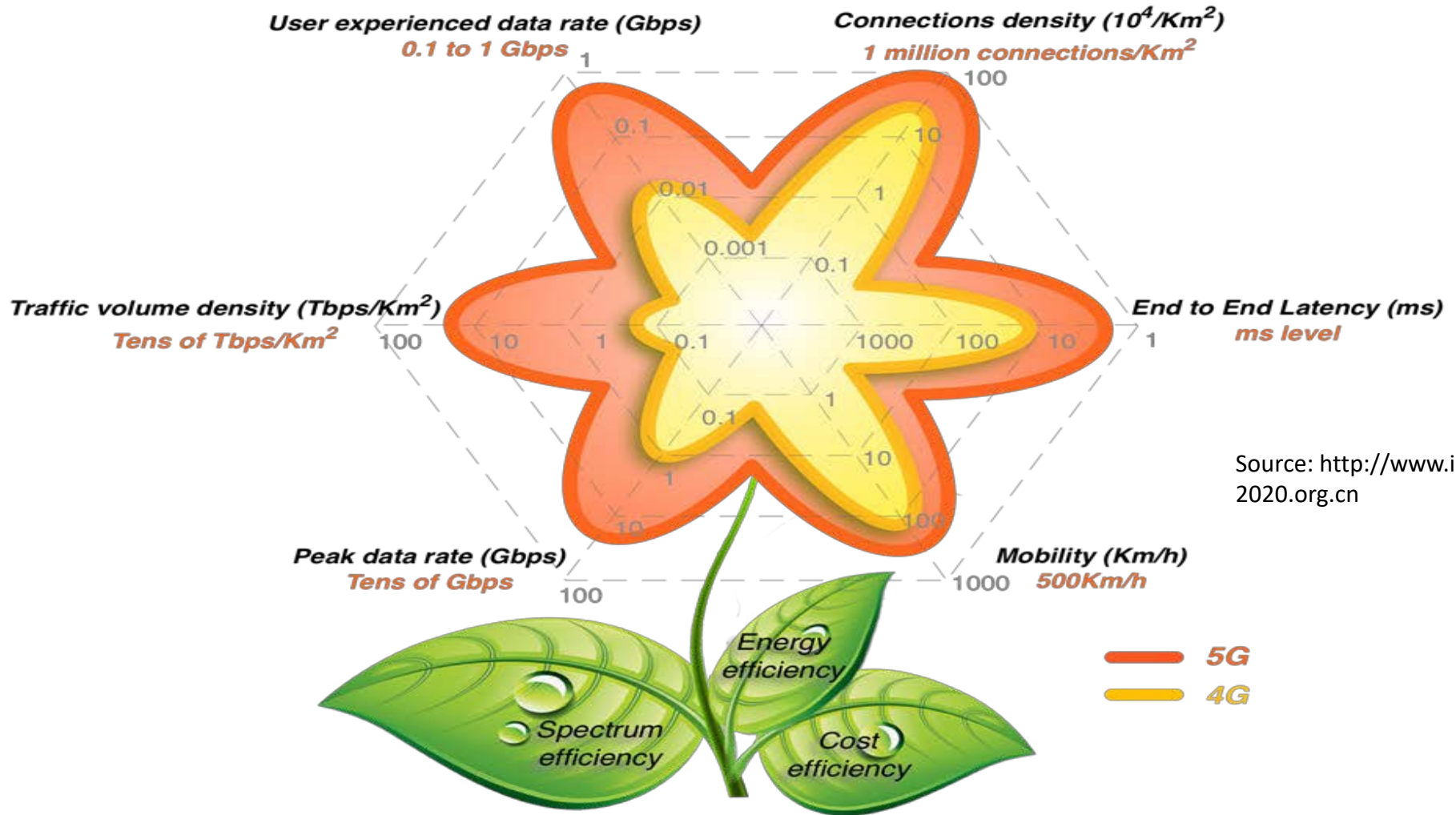
**We recall that in late nineteen nineties,
“dot.com” was unsuccessful, because
mobile phones and mobile internet were
not available!**

**After cell phones become popular,
Apple, Microsoft, Amazon, Facebook, etc.
now become the biggest companies!**

What is 5G?

- 5G means the advanced communication technology, which combines **hardware** of “satellite, optical fiber, server, base stations, mobile devices, sensor in terminals,” and **software** of “operating systems,” together it enables us to do all kinds of intelligent work.
- 4G has changed our daily life.
- 5G will change our society; politics, economy, arts & literature, health system, agriculture, industry, & **military**.

By 2020+, 5G is going to replace 4G



□ By 2017, 10B internet devices, 77B Apps... (DigiTimes, 10/30/2014)

Why 5G affects national security?

Data and signal can be transmitted,

- **Via air by satellites, but satellites can be shot down easily during war!**
- **Via underground by optical fiber lines. The manufacturing of optical fiber needs rare-earth elements!**
- **Via land surface by the network of base stations. Huawei in China is good in building base stations.**

洛杉磯—香港海底電纜 恐遭美封殺

【記者顏伶如／綜合報導】爲了設立連接洛杉磯與香港的海底電纜，美中企業夥伴已砸下數以百萬美元計的成本，但據華爾街日報報導，美方官員基於國家安全考量，正在設法擋下獲得臉書、谷歌等知名科技大企業支持的這項計畫。

消息人士指出，主持跨部門電子通訊審查小組的美國司法部，日前透露有意封殺洛城通香港海底電纜，理由是對於中方合作夥伴、企業總部位於北京的鵬博士電信傳媒集團存有疑慮，也對這條電纜持保留態度。

全長約一萬兩千八百公里的太平洋光纖電纜網路，絕大部分纜線已經透過船隻鋪設完成。根據報導，纜線鋪設的施工執照屬於臨時許可，今年九月即將到期。熟悉電子通訊審查小組事務的消息人士表示，在小組成員的杯葛之下，這條海底電纜極可能無法取得所需的執照。

若太平洋光纖電纜網路計畫受挫，將成爲遭電子通訊審查小組以國安考量加以封殺的首例，顯示美國主管電子通訊的政府機關，正對涉及中國的合作項目改採更嚴格的新規定。

5G Requirements - 5G之功能

Primary requirements: 首要功能

End-to-end latency (mille sec) - 低時延

Peak data rate (mobility) - 高速率

Traffic volume density - 巨量傳

Density of connection stations - 泛在網

Internet of everything - 萬物互聯

Energy efficiency - 低功耗

Secondary requirements: 次要功能

Security and reliability - 安全可靠

Low cost - 低價格

End-to-end latency

- Instant response; it depends on time-of – flight.
- On a human-less vehicle, the “Lidar” not “Radar”, requires a feed-back time of a few mille sec in order to avoid accident!
- In a chain of cars, if the leading car stops suddenly, the time gap to respond for all the cars behind is only about ten to hundred mille sec.

Density of connection stations

- China has about 600×10^4 base stations.
- Even rural villages have base stations, so cell phone can be used everywhere.
- No need to carry cash; you can pay by cell phone in no-man stores.
- You can make connections to almost everything, especially your home where artificial intelligent devices are implanted.

Mobile **Big Data** traffic growth— Industry preparing for 1000x increase

10^9 bits / sec

PREPARING FOR
1000x

DATA TRAFFIC
GROWTH

~2x

GROWTH

FROM 2010- 2011*



*Global growth, some regions grew more/less

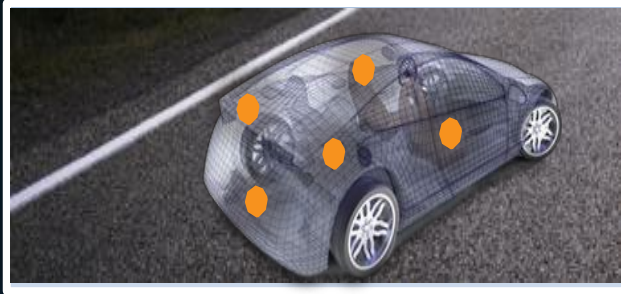
Traffic volume density

- Download is faster than upload.
- Instant download a book is no problem.
- With a high traffic volume density transfer, images will be much clear with a much better resolution. Same as music.
- We have instant news and weather report.

Internet of Things (IoT)

EVERYTHING AROUND US IS BECOMING INTELLIGENT & CONNECTED

Automotive



Industrial



Health & Fitness



Home



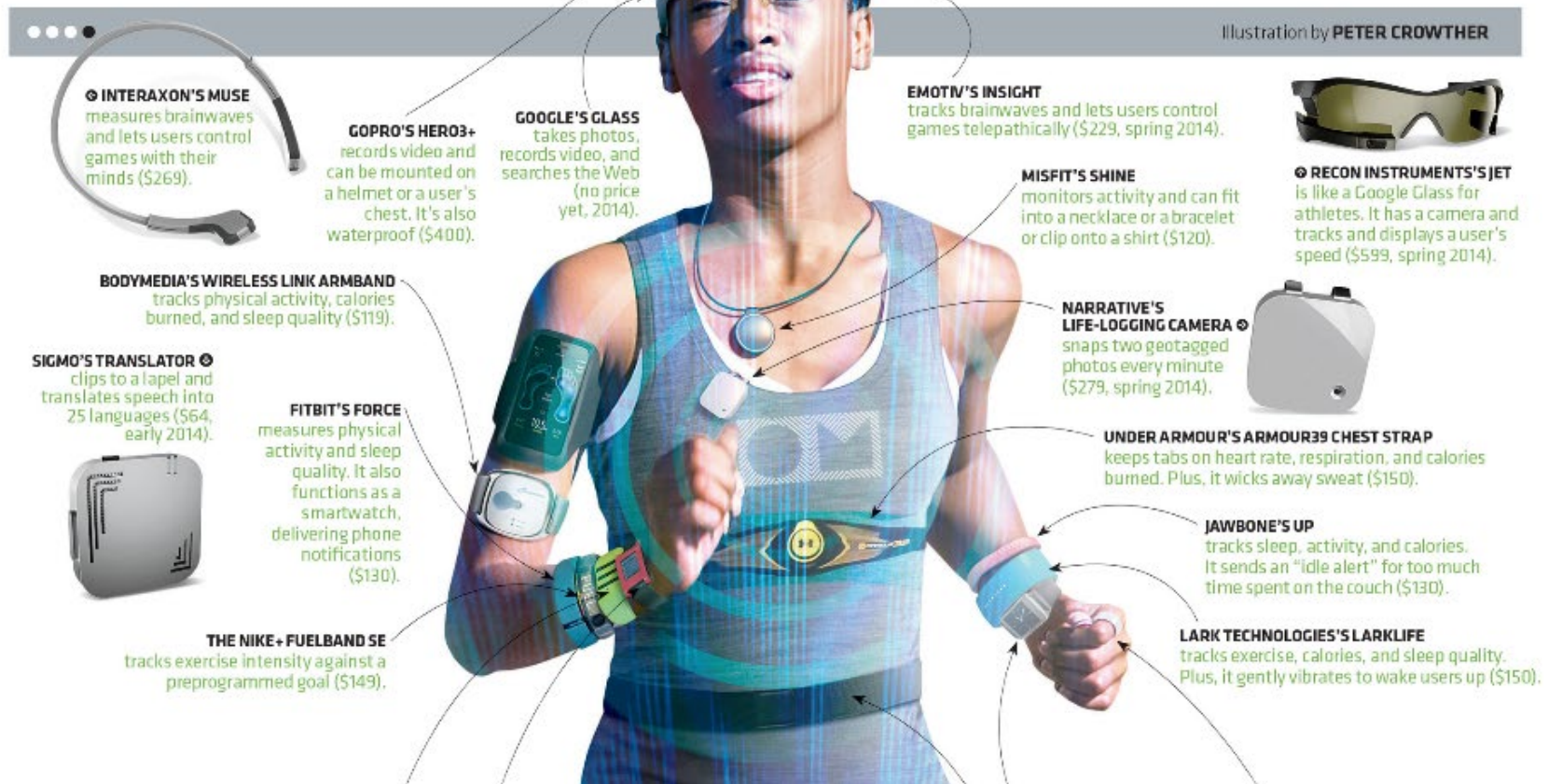
Increasing **Man-to-Man**, Man-to Machine, **Machine-to-Machine** (M2M) Communication

Mobile Internet

Companies race to create wearable devices for the whole body

THE FAMOUS LINE from Socrates that the unexamined life is not worth living has taken on a new meaning in the modern era. A wave of companies, many of them start-ups funded through sites such as Kickstarter and Indiegogo, is creating wearable electronic tracking devices for nearly every part of the human body, from brainwave-monitoring headbands to smart socks. And analysts expect the industry to explode over the next five years.

Retail revenue from wearable technology is predicted to jump from about \$1.4 billion in 2013 to as much as \$19 billion in 2018, according to a new study from Juniper Research. Here's a look at the products already on the market as well as a few of the items launching in the next year. If you want in, move fast: There's hardly any room left on the human body that isn't about to be covered by a device. —RYAN UNDERWOOD



Source: Inc Magazine, Juniper Research

NCC拍板 5G頻譜底價300億

翻了一倍 業者驚呆

9月4日受理申請

亞太電信：高於國際行情

【記者黃晶琳／台北報導】國家通訊傳播委員會（NCC）昨天拍板確定5G首波頻譜底價三百億元，較原本規畫的一五〇億元翻了一倍，電信業者直言「驚呆了」，應該拍賣幾天就會結束了，可能創史上最快紀錄。亞太電信指出，底價高於國際行情；遠傳總經理井琪則表示，高底價讓業者直接進入廝殺。



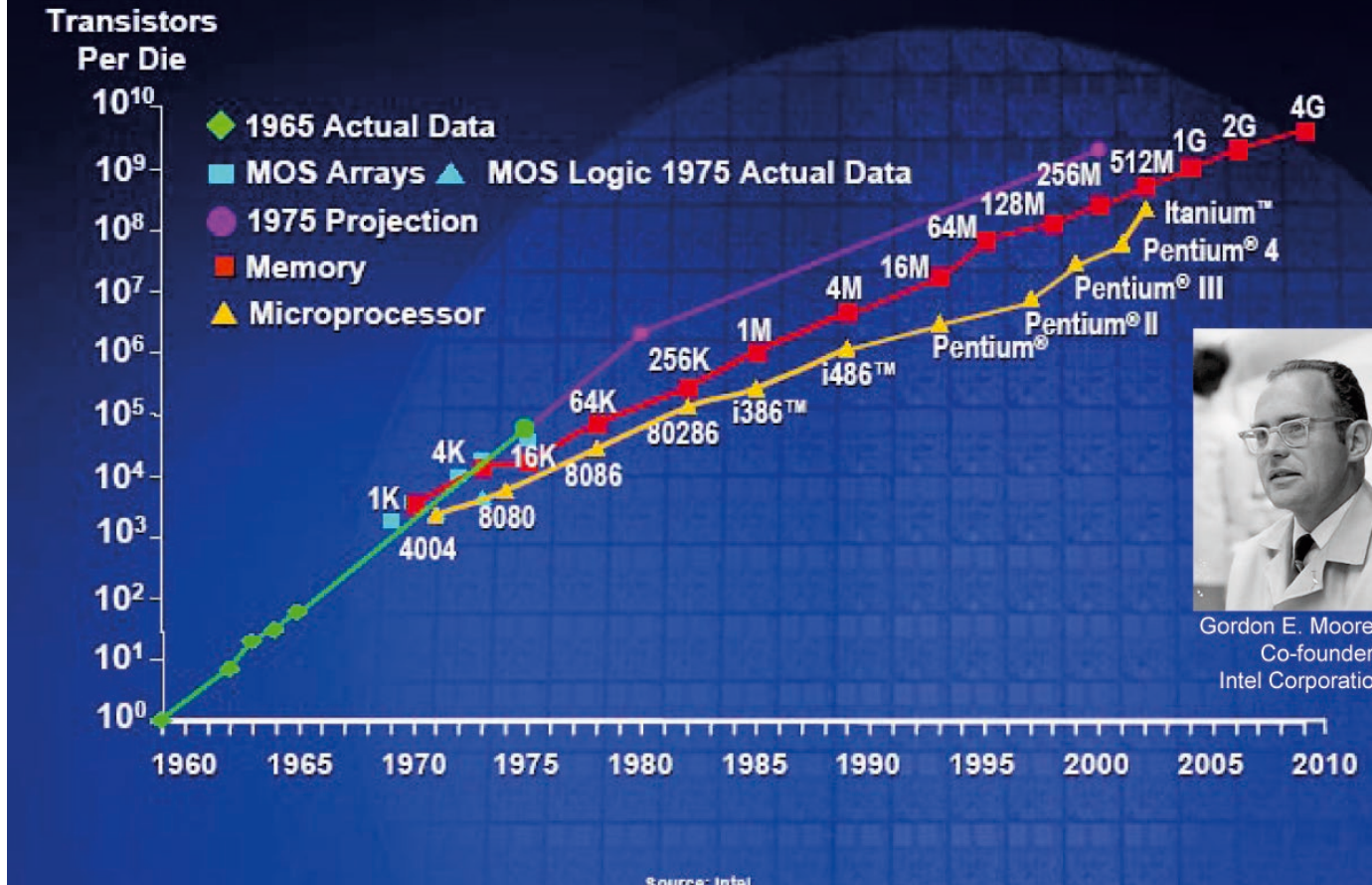
NCC昨天公布5G首波頻譜底價三百億元，九月四日受理業者申請，若釋照順利，台灣可望於明年中進入5G時代。

（法新社）

Wave frequency in 5G technology

- Sub-6; around 3 to 4 GHz, low frequency and long wave length; less interference.
- 24 to 300 GHz (毫米波), high frequency and short wave length; more interference due to scattering.
- Huawei in China is using sub-6 wave.
- US military is using sub-6 wave, then US industry will have to use high frequency wave.
- High frequency wave needs more base-stations (higher cost).
- Things will be clear in next year; 2020.

Integrated Circuit Complexity



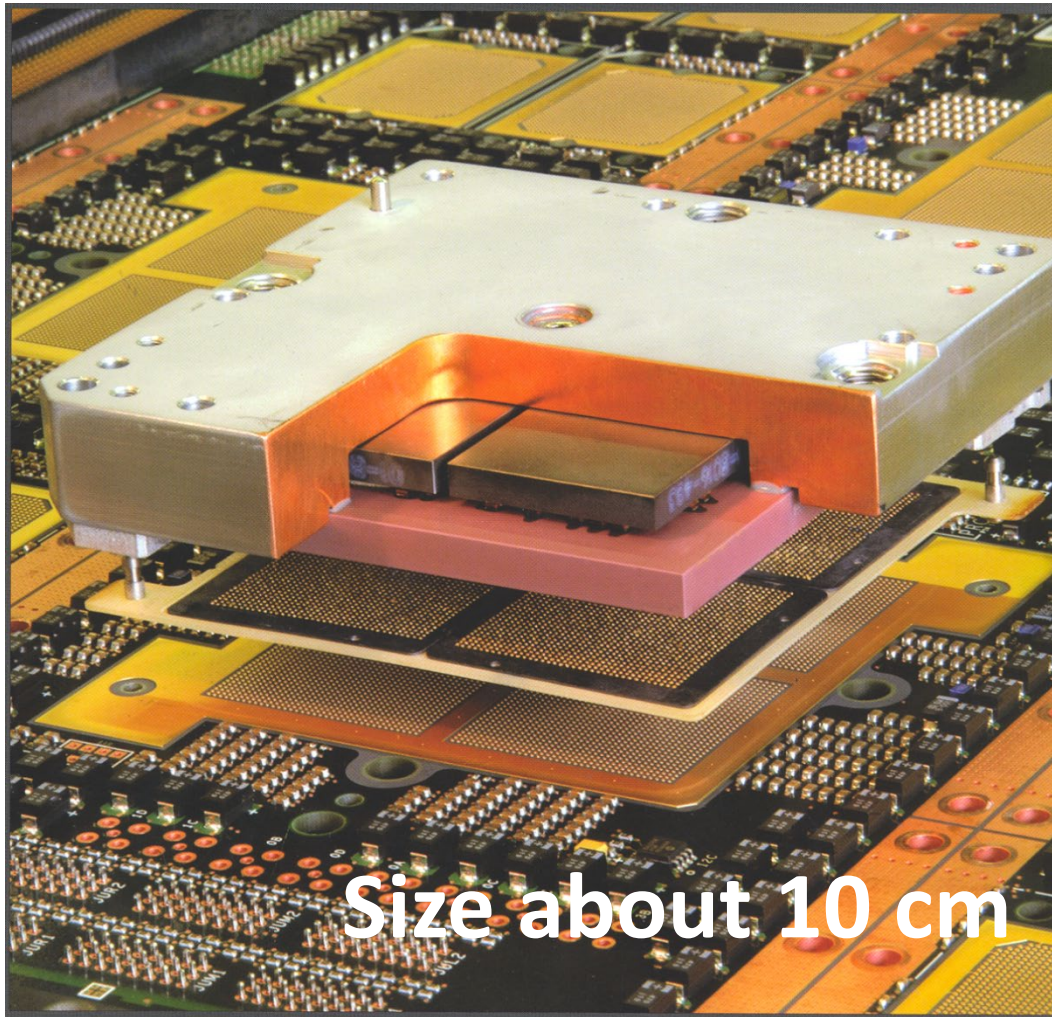
Moore's law: On-chip transistor density doubles every 18 to 24 months, without cost increase.

From 1970 to 1985, it increased from 1K to 1M.

From 1985 to 2005, it increased from 1M to 1G.

Two most important contributions of Moore's law

- 1). It enables the development of mobile technology because of physical size reduction.**
- 2). The cost of transistor is dirt cheap because of density reduction without cost increase.**



Size about 10 cm

Physical size reduction

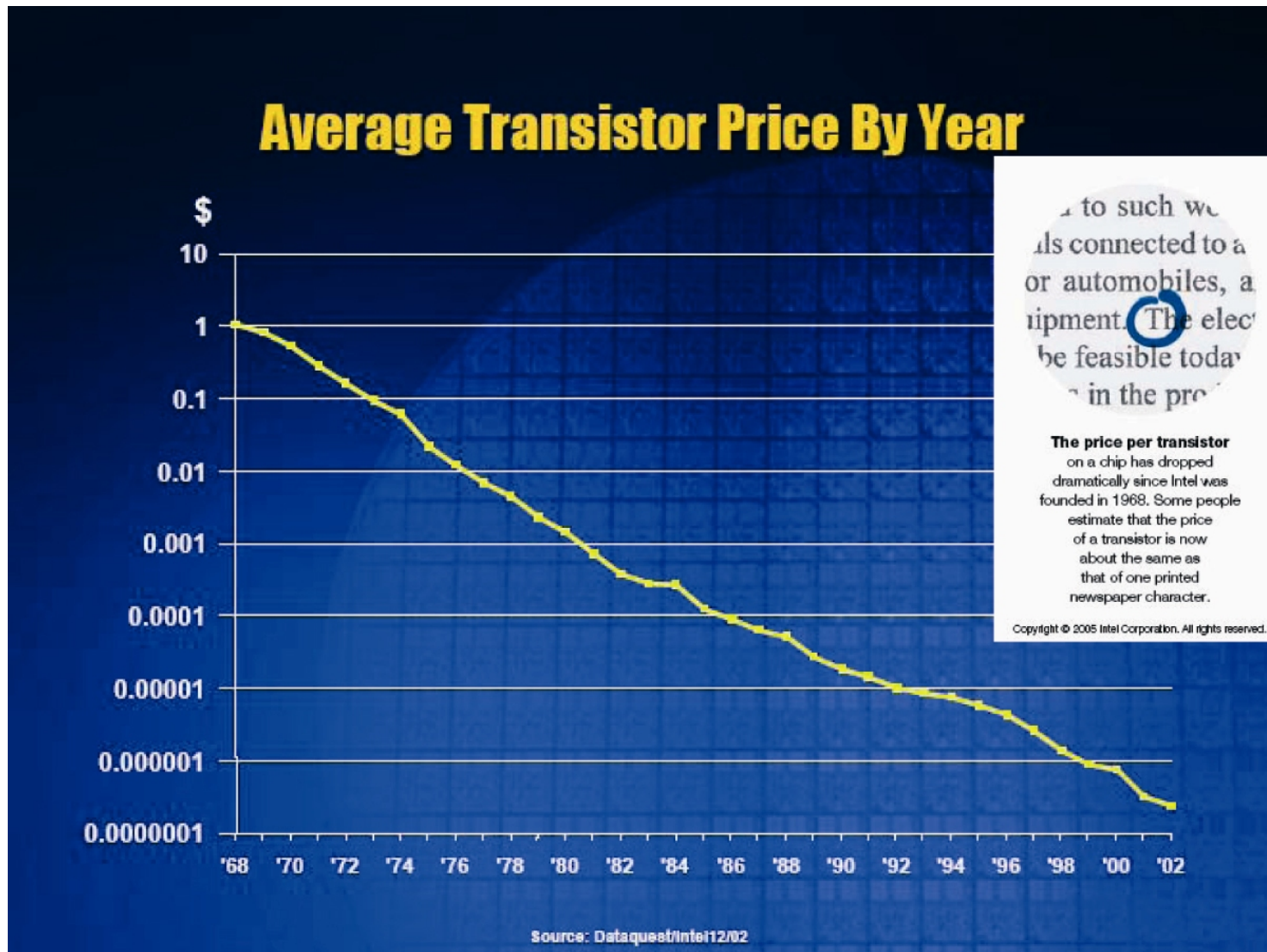
There are 110 Si chips in the module of a mainframe computer in 2002.

**IBM J. of R&D.,
Nov., 2002.**

If we can replace the 110 chips by 1 chip, we can make the mobile computer!

Also replace keyboard by finger-touch.

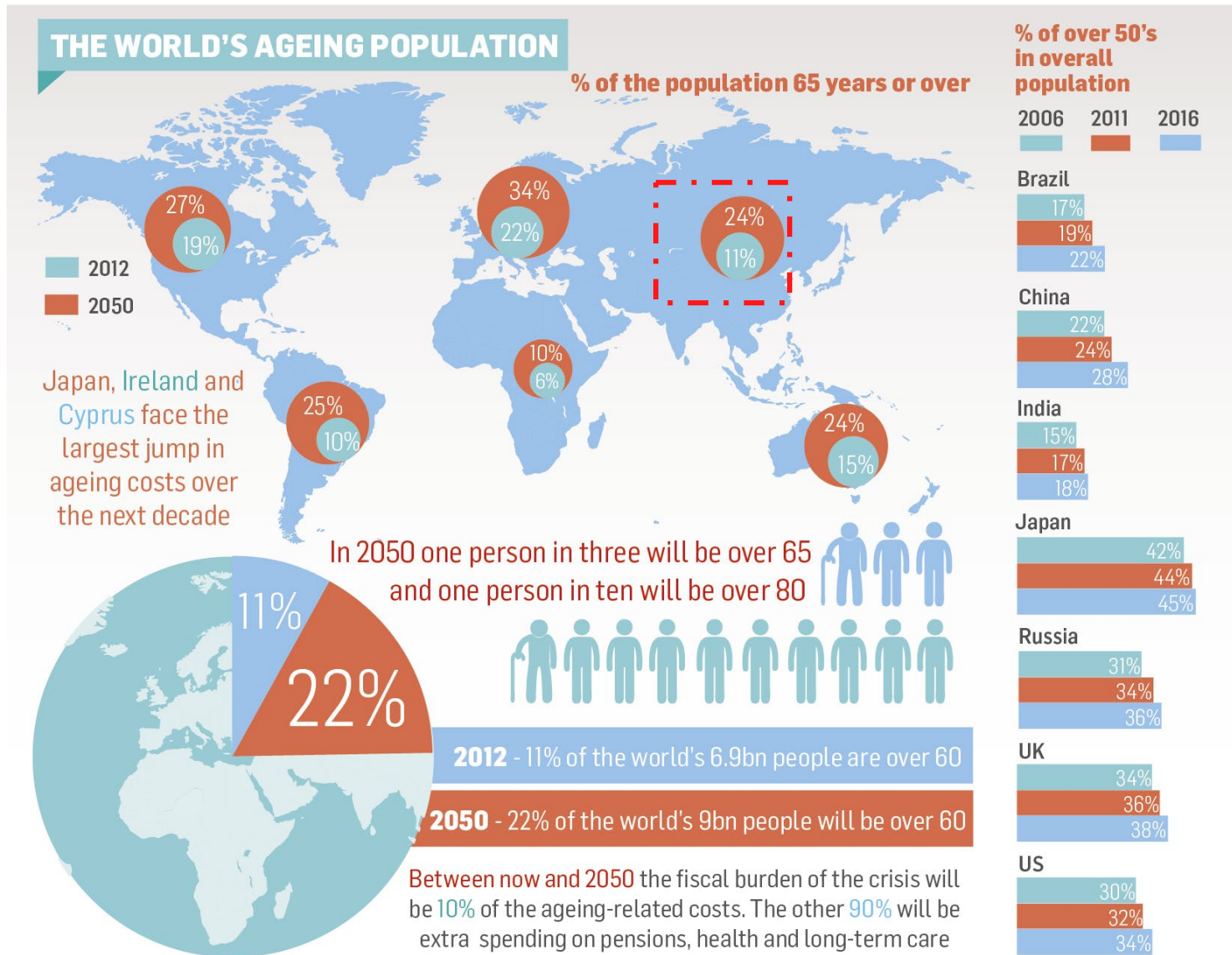
All 5G requirements depend on a key factor that transistors is dirt-cheap!!



Transistor is dirt cheap!

- The cost per transistor is cheaper than the printing of an alphabet on a news paper!
- **The problem in China** is how to make transistors cheaper than those made in US, Taiwan, and Korea!
- **The problem in US** is how to find new and huge applications in order to use up all the extremely large amount of transistors.
- After mobile consumer electronic products, new inventions in bio-medical applications will be critical in the future use of transistors.

Global Ageing Population



i-health is coming!

Vital data of health:

- **Body temperature**
- **Heart beat**
- **Blood pressure**
- **Oxygen content in blood for “diabetes”**
- **Sugar content in blood for “diabetes”**

We need non-invasive methods to detect them, because urine or mouth-water has low oxygen content.

The link between microelectronics and bio-medical applications will be the most important technology advance in the future.

Below, we shall discuss AI with an example!

Automatic toilet, 自動型馬桶

- **Automatic toilet is popular in Japan.**
- **The sit cover of the toilet can be warm, and a nozzle can spread water to clean you.**
- **It performs a pre-determined set of functions.**
- **3G and 4G technology can do it.**

Intelligent toilet, 智慧型馬桶

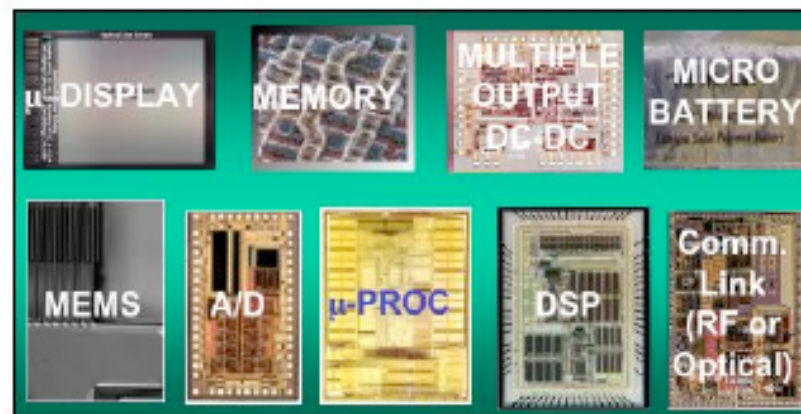
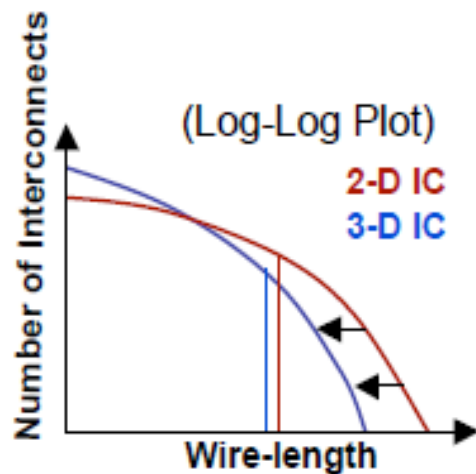
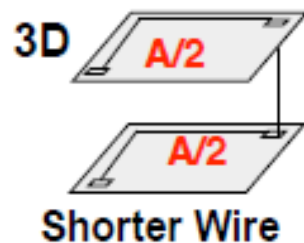
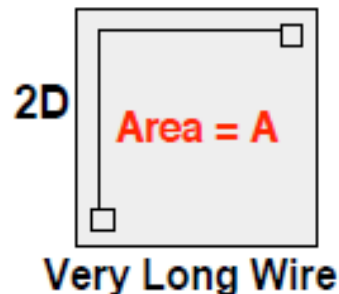
- An intelligent toilet can recognize that you stand in front of it. If you face it, it will open two covers, but if your back face it, it will open one cover!
- After you finish urine, the sensor in the toilet can detect sugar content (diabetes), and acid content (gout). It can send you and your doctor an email.
- The toilet can make a right decision; it takes 5G technology to do so!

AI applications

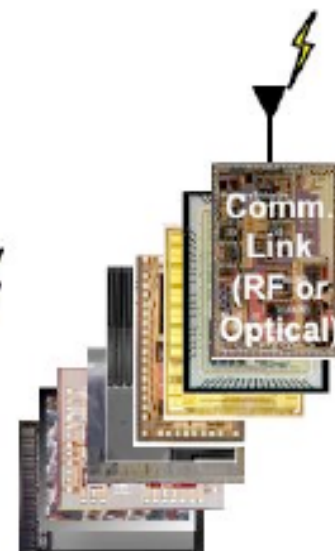
in mobile consumer electronic products

- **A rapidly growing industry in 5G technology.**
- **Low power consumption (battery-limited), small form factor, and multi-functionality.**
- **Heterogeneous integration; CMOS and photonic chip, etc.**
- **3-Dimensional Integrated Circuits (3D IC).**
- **What is 3D IC?**
- **Can “AI” help improve reliability in 3D IC?**

3-D Integration: Motivation



2-D System

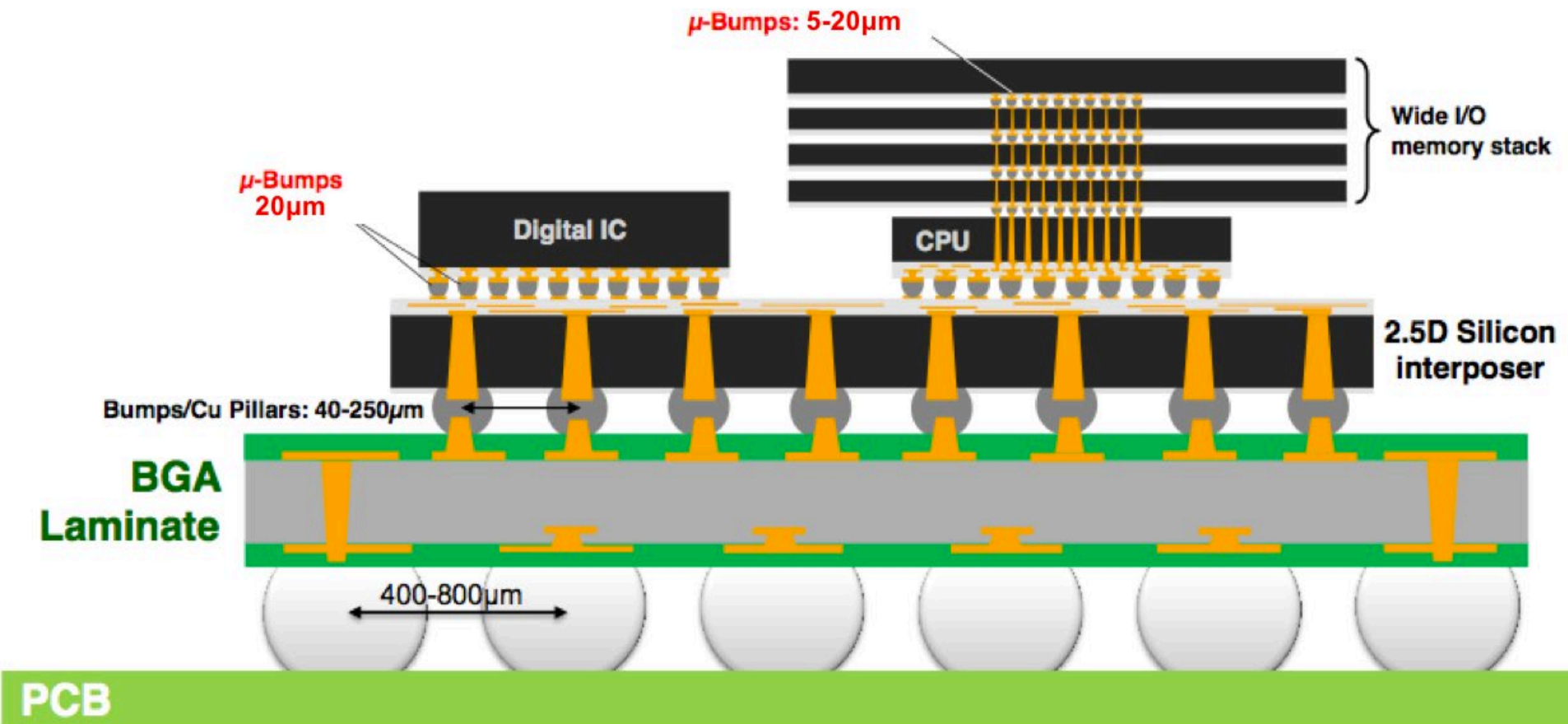


3-D System

- Integration of heterogeneous technologies possible, e.g., memory & logic, optical I/O
- Reduce Chip footprint
- Replace long horizontal wires by short vertical wires
- Interconnect length \downarrow and therefore $R, L, C \downarrow$
 - Delay reduction
 - Power reduction

Schematic diagram of 3D stacking of chips

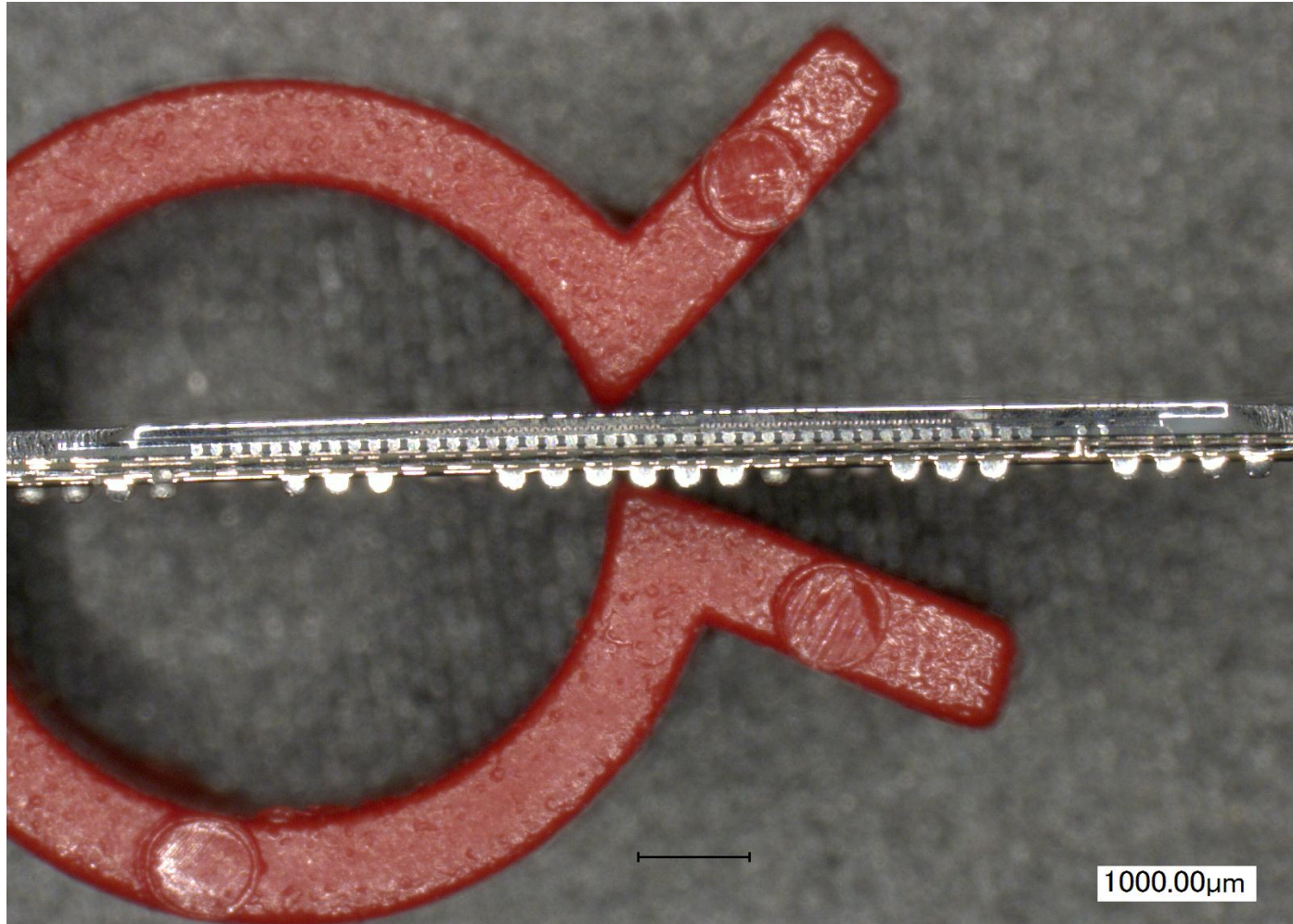
CoWoS (chip-on-wafer-on-substrate)



I/O memory stacks integrated with IC and CPU on the same package

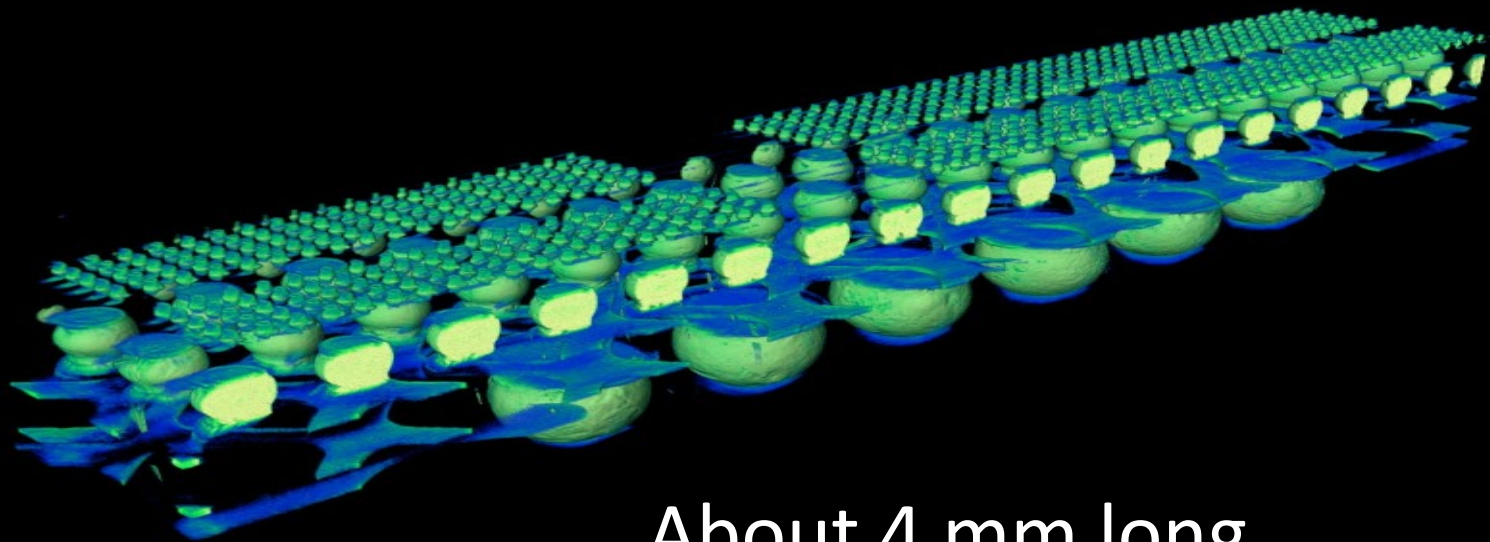
Courtesy of Yole Development, Lyon, France

Optical image of the cross-section of a 3D IC test sample (**1 cm long**)



Courtesy of Miss Yingxia Liu, UCLA

Advanced Light Source Lawrence Berkeley National Laboratory



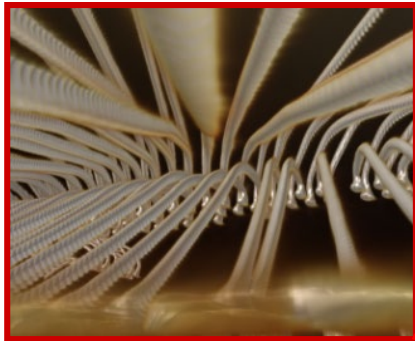
About 4 mm long
And 0.5 mm wide and thick

To inspect a 3D IC structure?

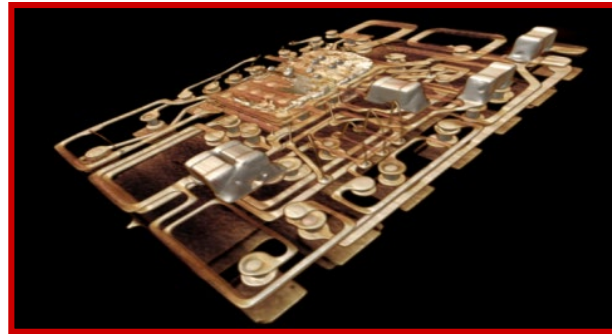
- We use x-ray to inspect our lung for cancer or tuberculosis, but it is 2D projection.
- To inspect the internal of a 3D IC structure, we need x-ray tomography or x-ray graphic processing unit; **X-GPU!**
- For machine learning of the tomography, we use synchrotron radiation facility or a table top x-ray machine with high resolution.

3D X-ray Images in IC Packages

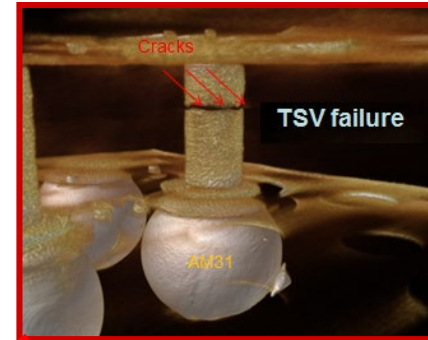
bond wire



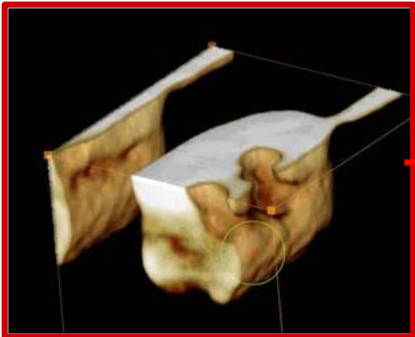
module



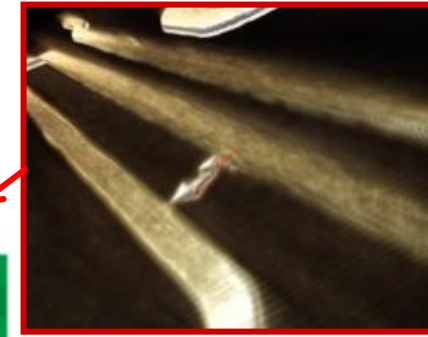
TSV



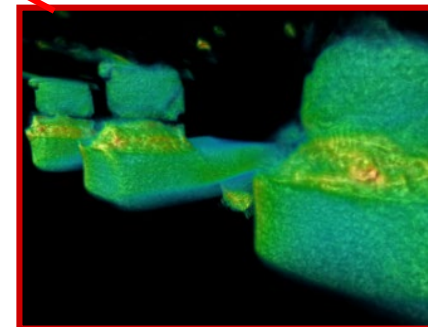
Cu pillar



trace



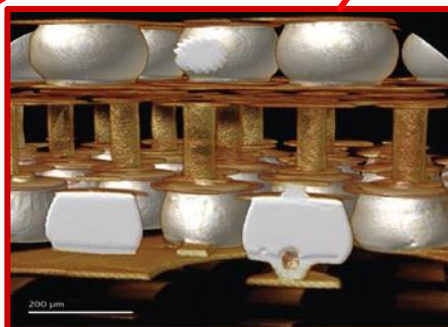
bump



bump



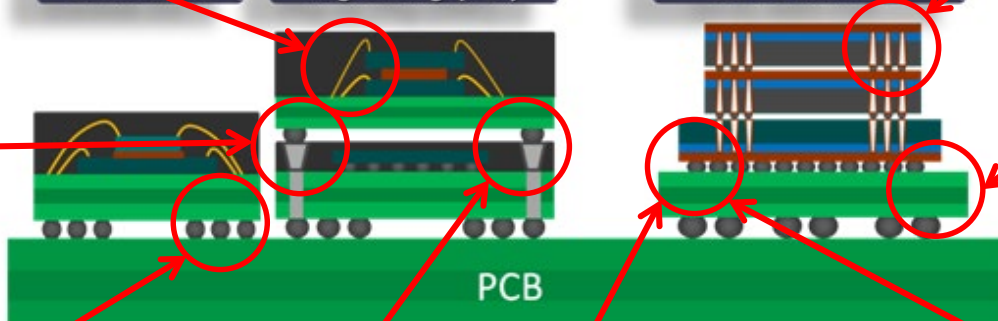
PoP



Stacked die

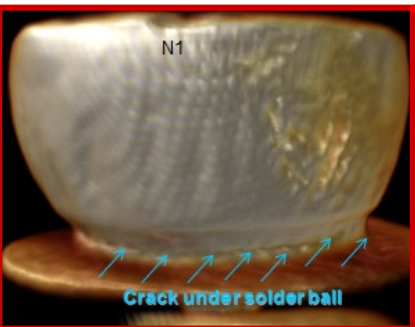
Pkg on Pkg (PoP)

3D-IC with TSV



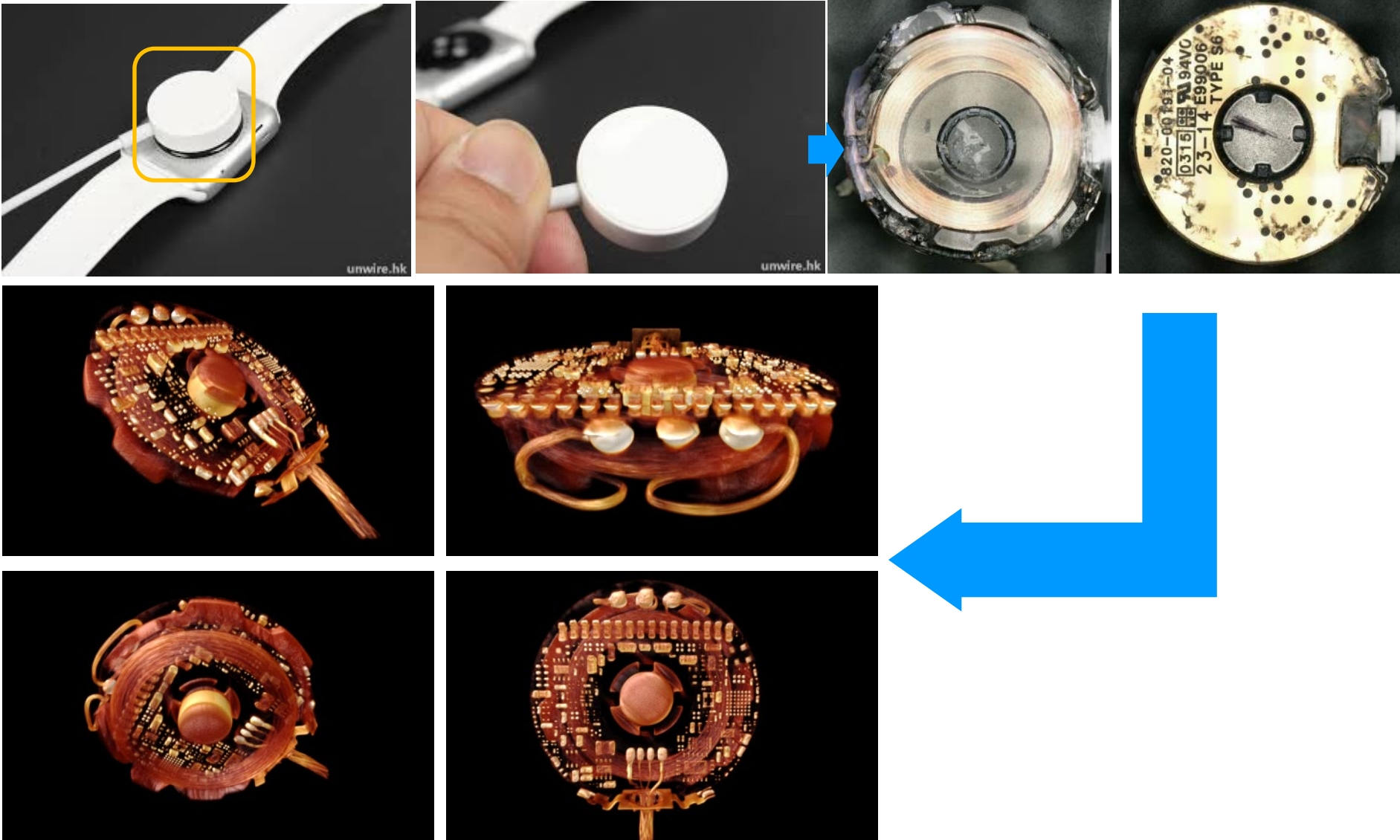
PCB

BGA ball



Courtesy of Dr. YF Hsieh, MA Tek in Hsinchu, Taiwan

3D X-ray Image of Apple Watch



Courtesy of Dr. YF Hsieh, MA Tek, Hsinchu, Taiwan



Kelvin probe: Courtesy of Dr. Y. F. Hsieh, MA Tek, Hsinchu

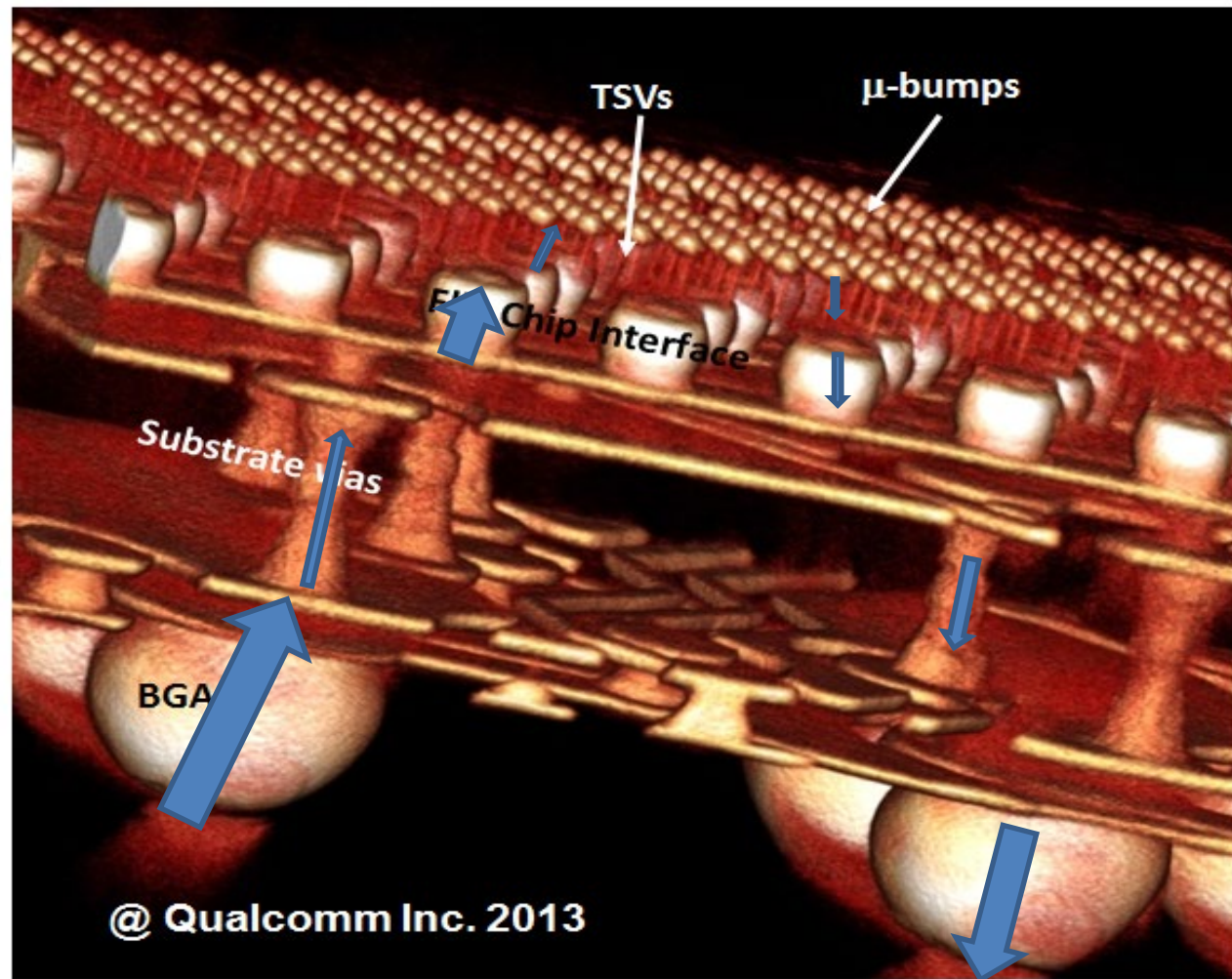
Goal of Reliability

- **1st**; To find weak-link or early failure in the system. They are **unacceptable or abnormal** failures.
- **2nd**; To determine mean-time-to-failure (MTTF). They are **acceptable or normal** failures.

Reliability tests

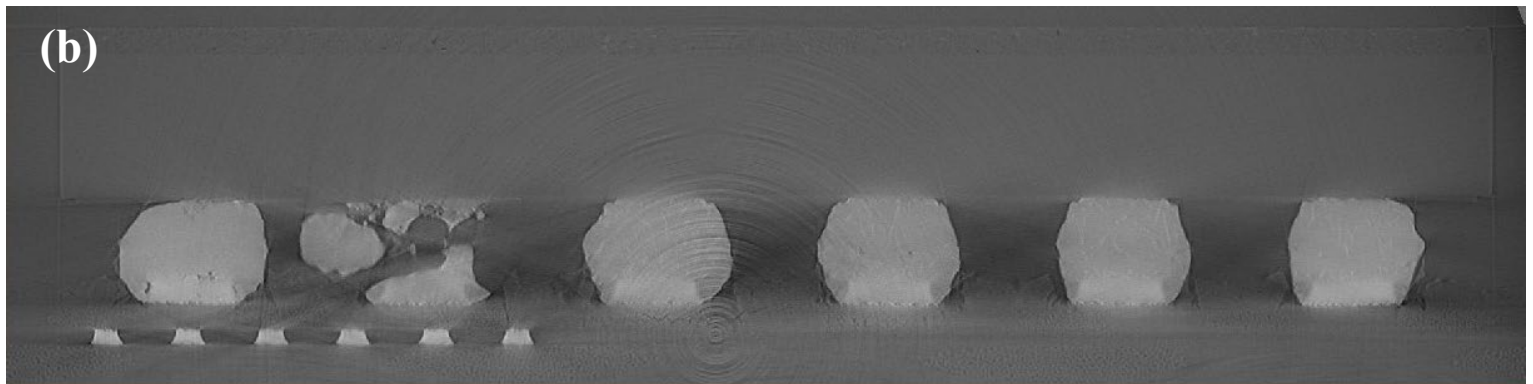
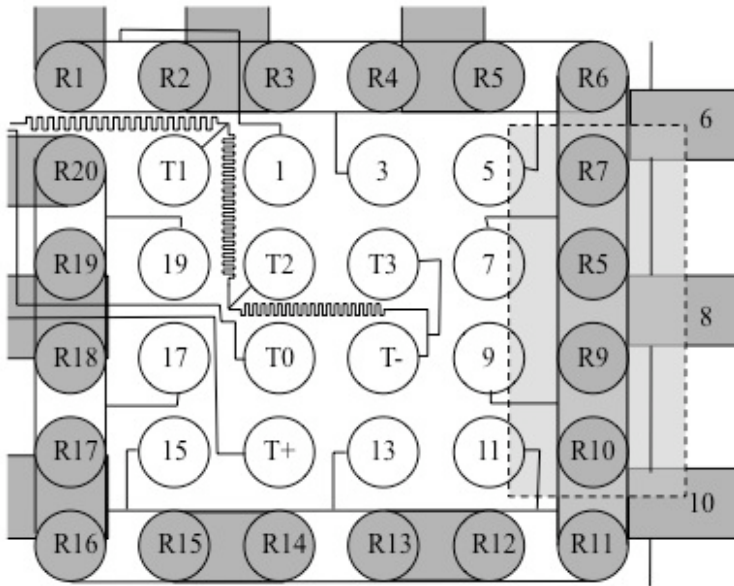
- We must pass electric current as a function of current density, time, and temperature to induce failure.
- We must have a large set of data to obtain a distribution (Weibull), so that mean-time-to-failure (MTTF) can be determined.
- The kinetic activation energy can be decided by using irreversible processes.

Second level chip
First level chip
Substrate



System level interconnect electromigration study;
Blue arrows indicate circuit path.

Where is the **weak-link in the interconnect?**



Electromigration failure in a solder joint

Black's equation of mean-time-to-failure

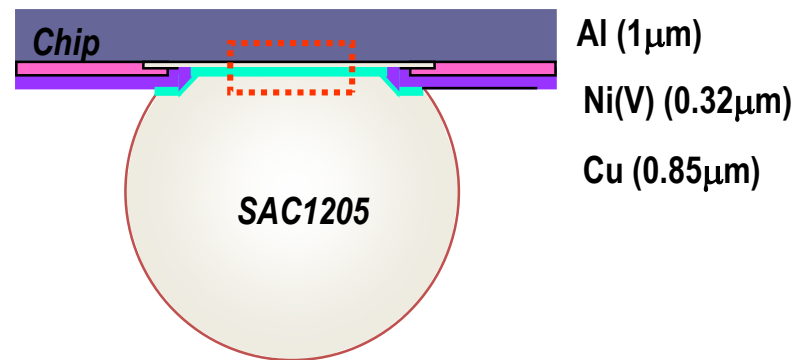
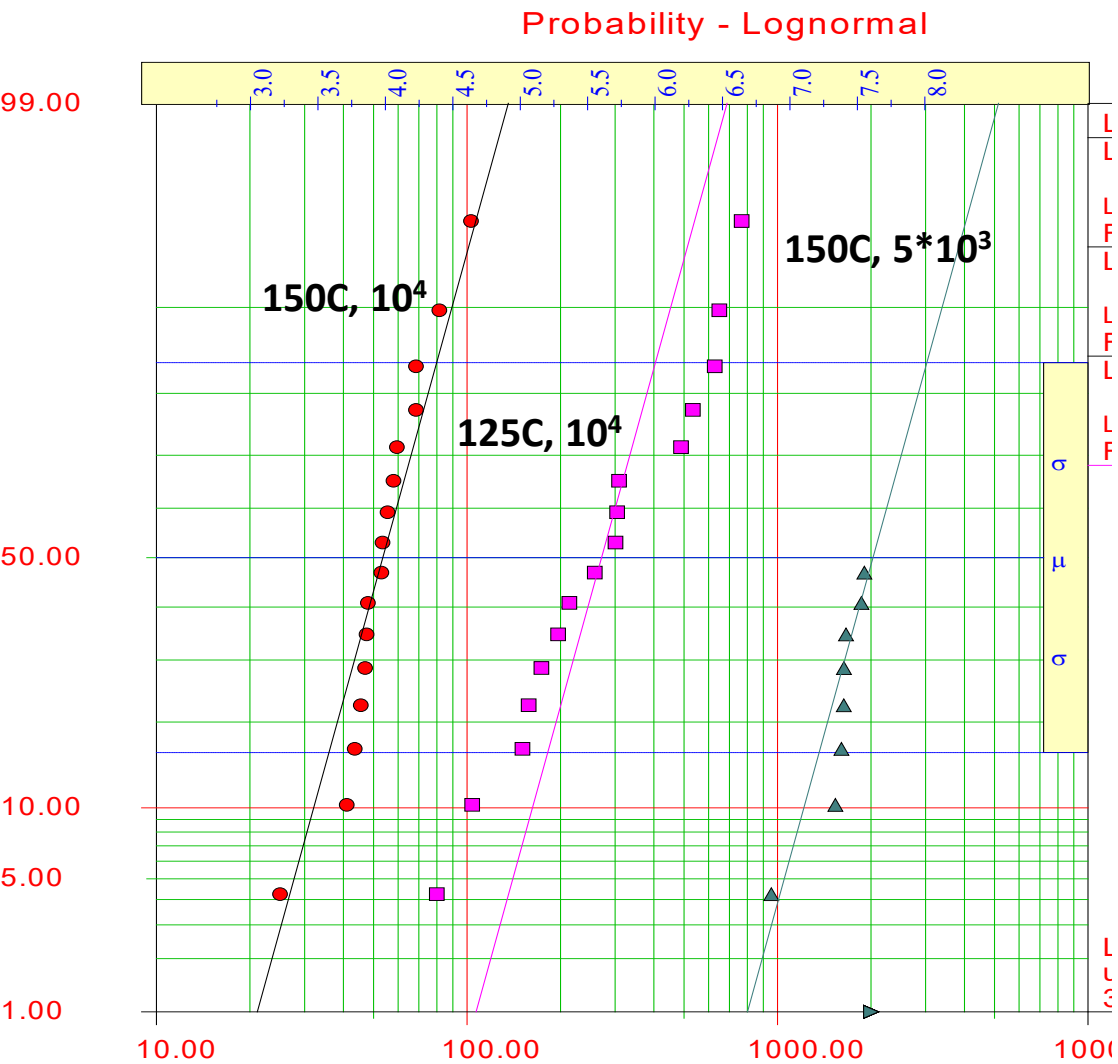
$$MTTF = A(j^{-n})\exp\left(\frac{E}{kT}\right)$$

A is pre-factor

n is current exponential, typically n = 2

E is activation energy of atomic diffusion

1. [K. N. Tu and A. M. Gusak," A unified model of mean-time-to-failure for electromigration, thermomigrationm, and stress-migration based on entropy production", J. Appl. Phys., 126, 075109 \(2019\).](#)



T	150C, 10^4A	125C, 10^4A	150C, $5 \times 10^3\text{A}$
η	61.7	368.5	2149.6
MTTF	48.9	288.5	1700.6

From Dr. Luhua Xu (UCLA)

Goal of AI in 3D IC reliability

- In the future, when a new device is in production, we examine it by X-GPU and we can identify quickly the weak-link, where early failure occurs.
- For MTTF; it is no need to conduct the time-dependent and time-consuming reliability tests.
- AI can provide time-independent reliability to save time of the study.

Summary

- **5G technology will affect our society.**
- **AI applications are everywhere.**
- **The successful use of 5G + AI depends on our basic training in mathematics, physics, chemistry, biology, Chinese, and English!!!**

Thank you !