SITRI

Challenges of IC Materials Call for Collaborations
以合作迎接集成电路材料的挑战

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Vice President Advanced
Process and Materials

Outline

- Advances in semiconductor technology are built on the advances of materials
- Growth of China Semiconductor Industry needs strong Chinese semiconductor materials companies
- Innovations in semiconductor materials and growth of the industry require collaborations
- SITRI provides a platform for collaborations in semiconductor materials

Semiconductor industry is built on semiconductor materials 半导体产业是建立在半导体材料的基础上的

Properties of Semiconductor Materials

Semiconductor Materials		Bandgap (eV)	Melting Point (K)	Main Applications
1st Generation	Ge	1.1	1221	Low V, low f, mid power transistor, photonics
	Si	0.7	1687	
2nd Generation	GaAs	1.4	1511	MW&mmW Devices, LED
3rd Generation	SiC	3.05	2826	1. High T, high f, Radiation resist, Power devices 2. Blue, green and violet LEDs, lasers
	GaN	3.4	1973	
	AlN	6.2	2470	
	ZnO	3.37	2248	
4th Generation	Diamond	5.5	>3800	Ultra-high power devices
	Ga_2O_3	4.85	1795	

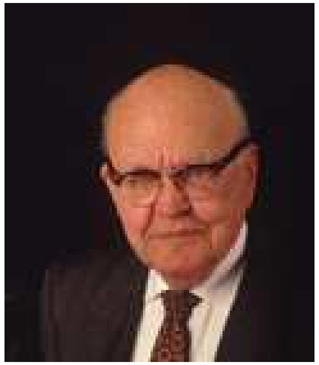
From public information

From the Discovery of Semiconductor Materials
从半导体材料的发现

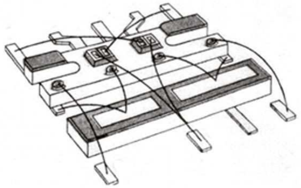
Thomas Johann Seeback	Michael Faraday	Alexadre Edmond Bacquerel	Willoughby Smith	Karl Ferdinand Braun
1821	1833	1839	1873	1874
AgCl	Ag2S	AgCl， AgBr	Se	Metal Sulfide
Thermalelctric Effects		Photovoltaic Effects	Optoelectric Effects	Rectify Effects

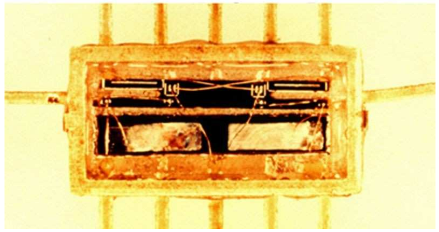
To the birth of Integrated circuits 到集成电路

William Shockley，Brattain， Bardeen 1947， 锗晶体管

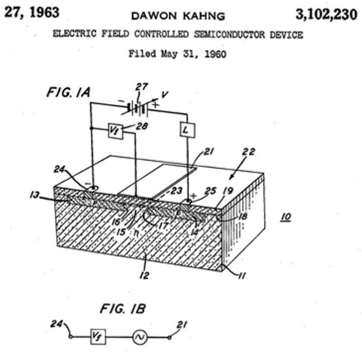


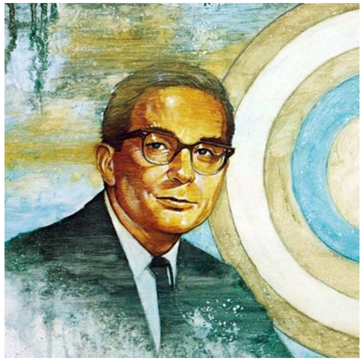
Jack Kilby 1958 第一次同一衬底**2**个不同器件，锗





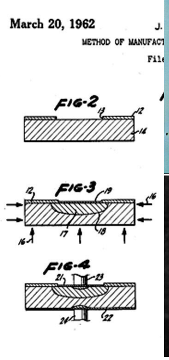
Bell Lab 1959 硅基**MOS**

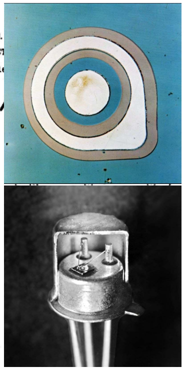




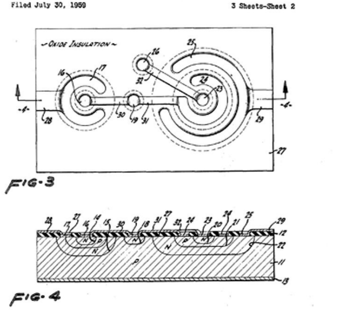
Jean Hoenri 1959 平面工艺

Robert Noyce 1960 硅基平面工艺



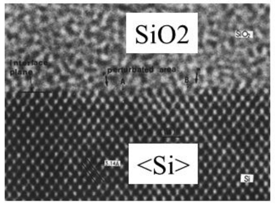


硅谷**8**人帮，**1964**，平面工艺连接不同器件



Si-SiO2 – The perfect interface

Properties of SiO_2



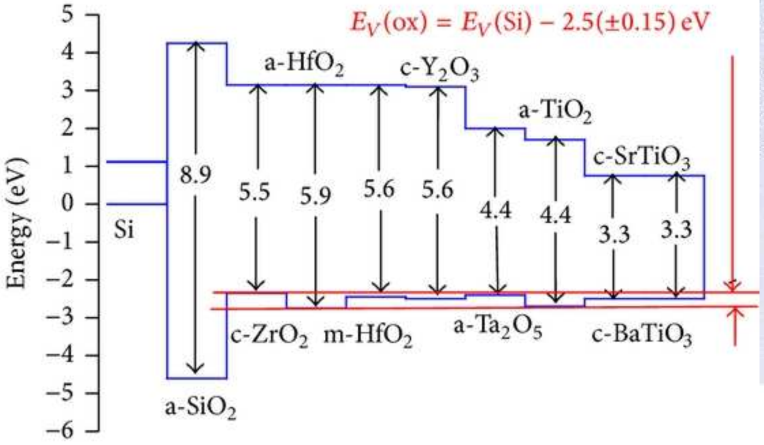
Thermal SiO_2 is **amorphous**.
Weight Density = 2.20 gm/cm³
Molecular Density = 2.3E22 molecules/cm³

Crystalline SiO_2 [Quartz] = 2.65 gm/cm³

(1) Excellent Electrical Insulator
Resistivity > 1E20 ohm-cm Energy Gap ~ 9 eV

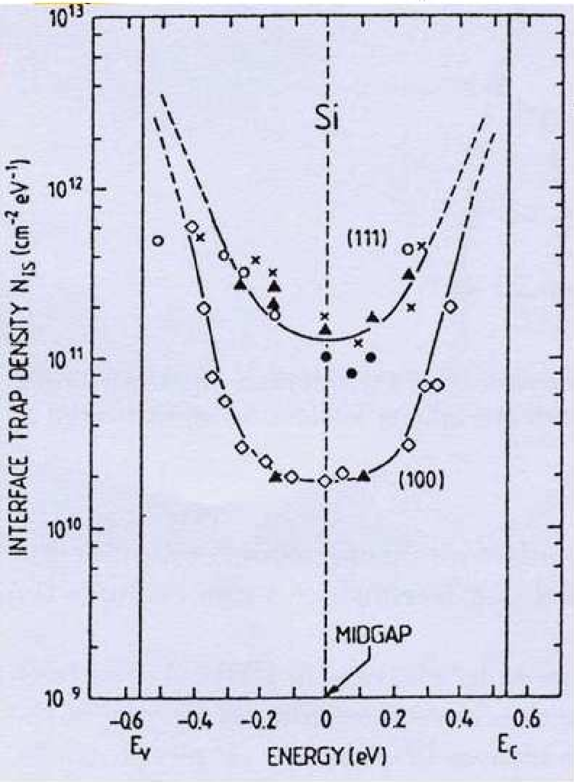
(2) High Breakdown Electric Field
> 10MV/cm

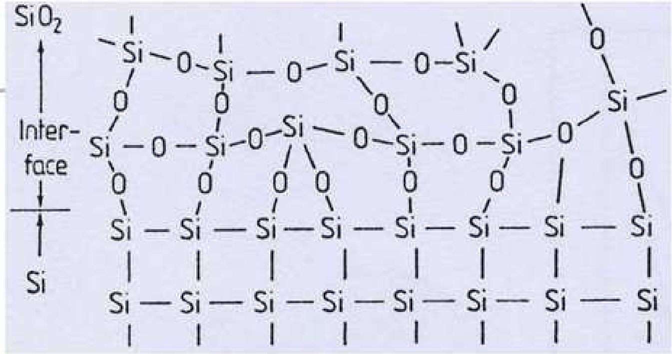
(3) Stable and Reproducible Si/SiO_2 Interface



$Si-SiO_2$ Interfaces

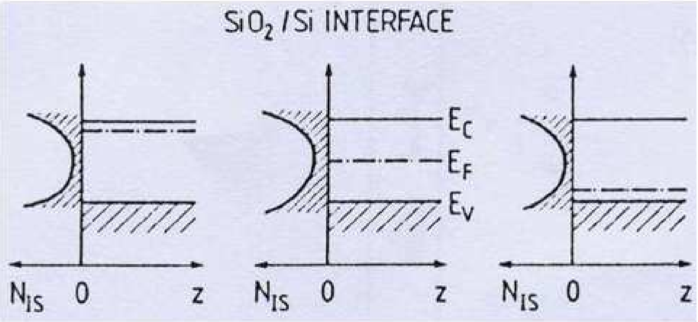
Interface state density can be down to 10^8 cm^{-2} eV^{-1} near midgap



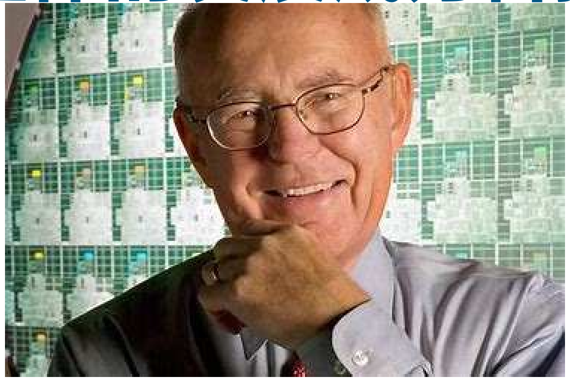


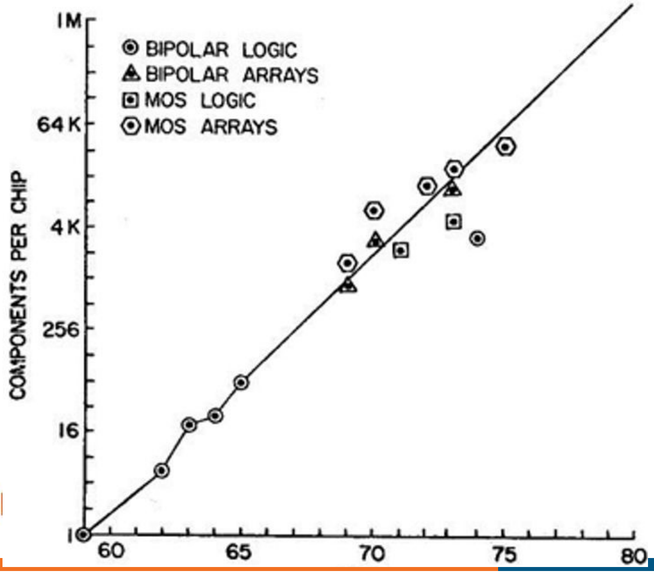
Si(100) is preferred

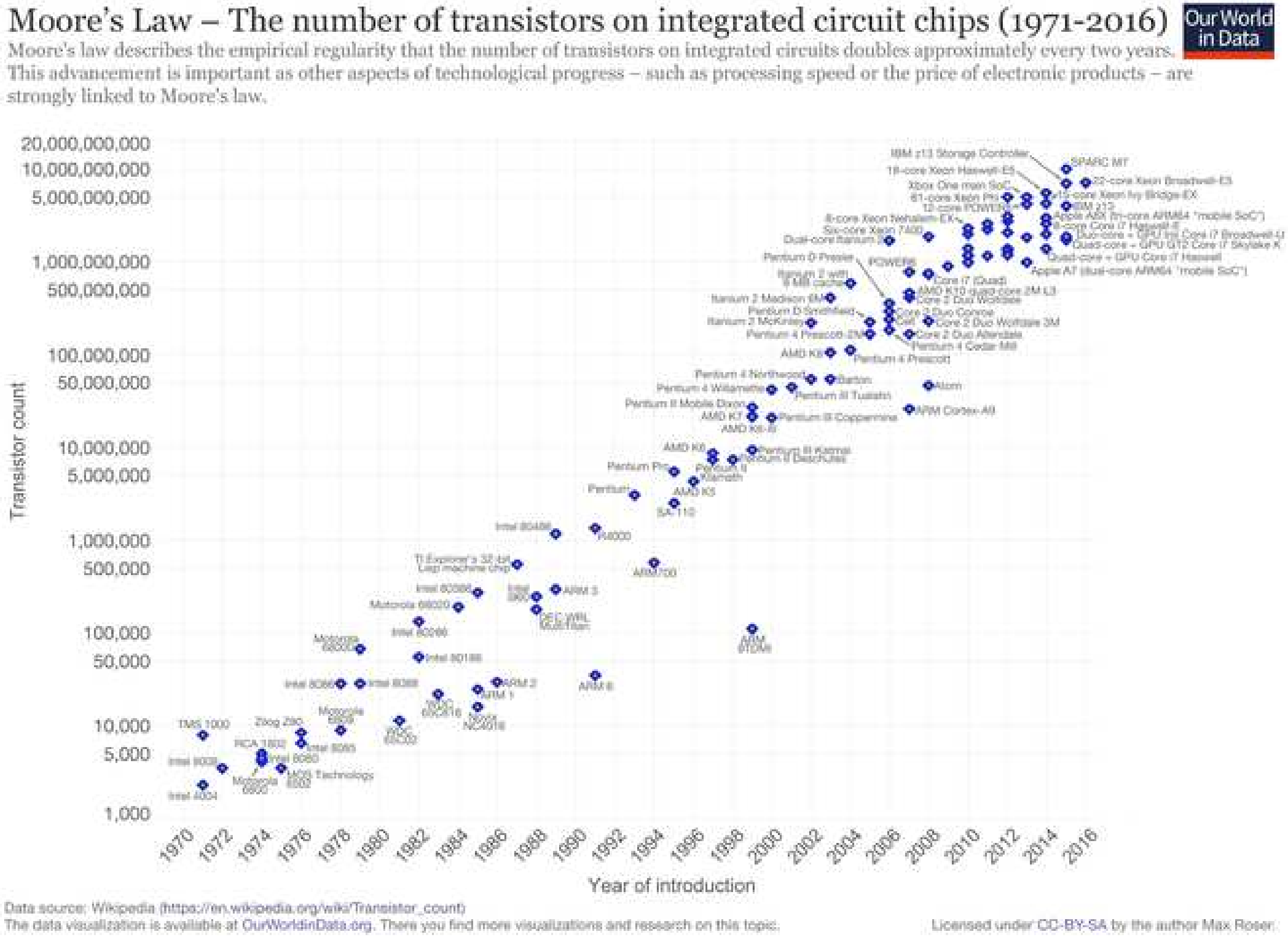
Flat band at $Si-SiO_2$ interfaces



IC industry grows by the Moore’s law – a technological and economic miracle 集成电路按摩尔定律的发展成为科技经济奇迹





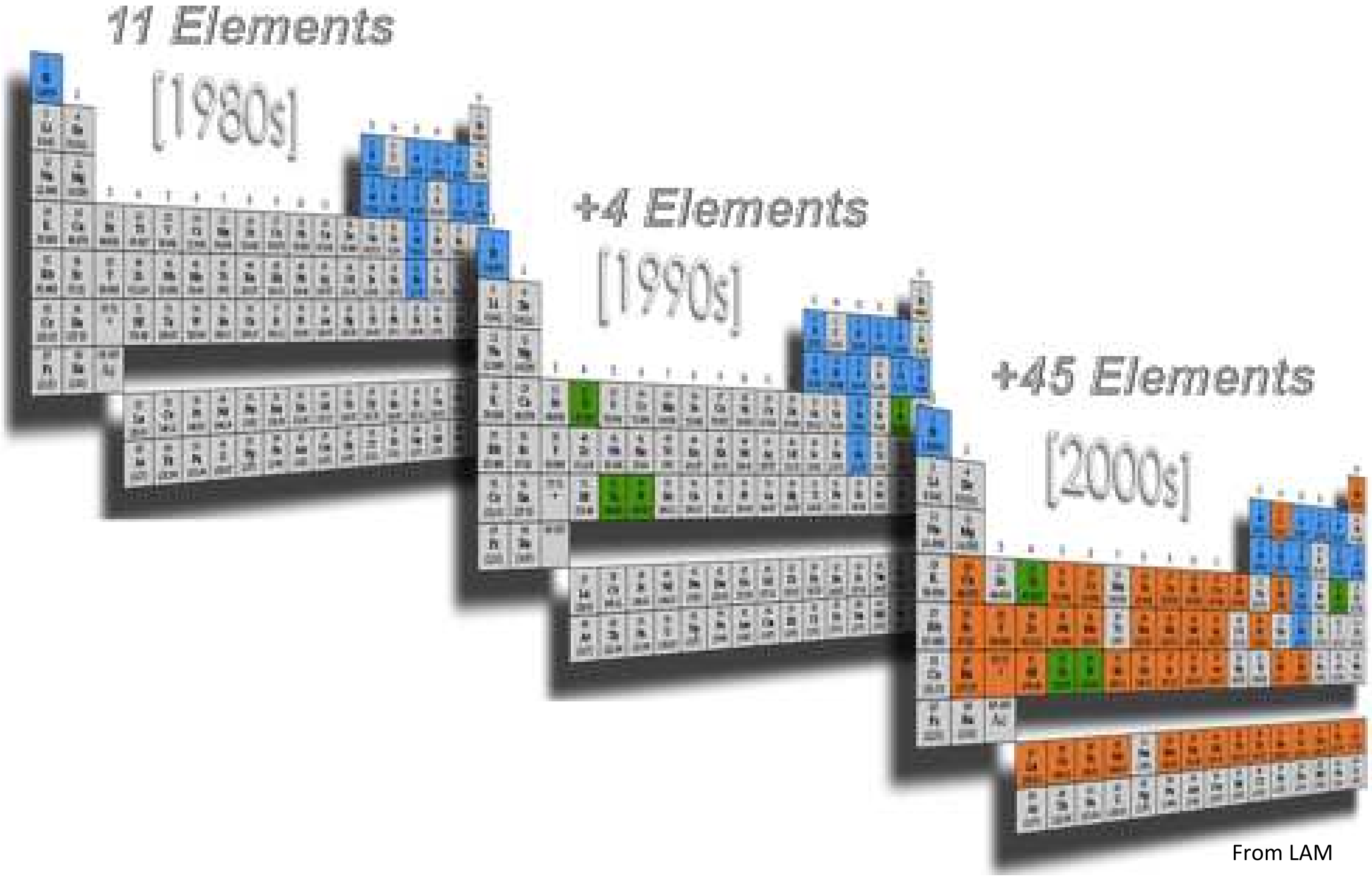


Moore’s Law – The number of transistors on integrated circuit chips (1971-2016)

Moore’s law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore’s law.

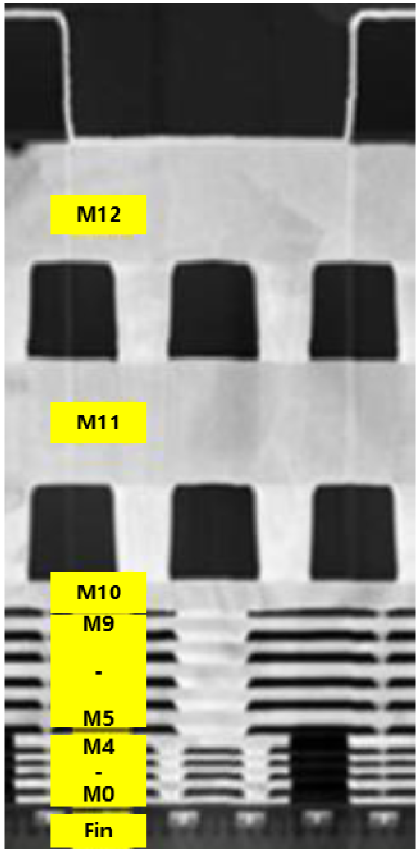
Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.

More Moore to More than Moore will continue to rely on new materials and new innovation of materials 超越摩尔和后摩尔时代离不开更多的材料和材料的创新

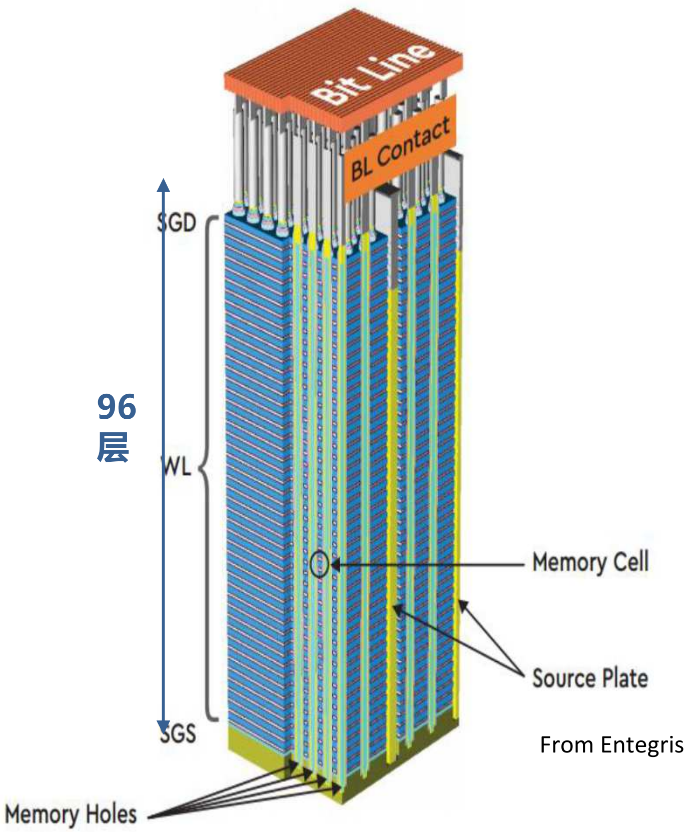


From LAM

The most complex and precise processes of mankind 集成电路制造是人类最复杂和最精密的工艺过程



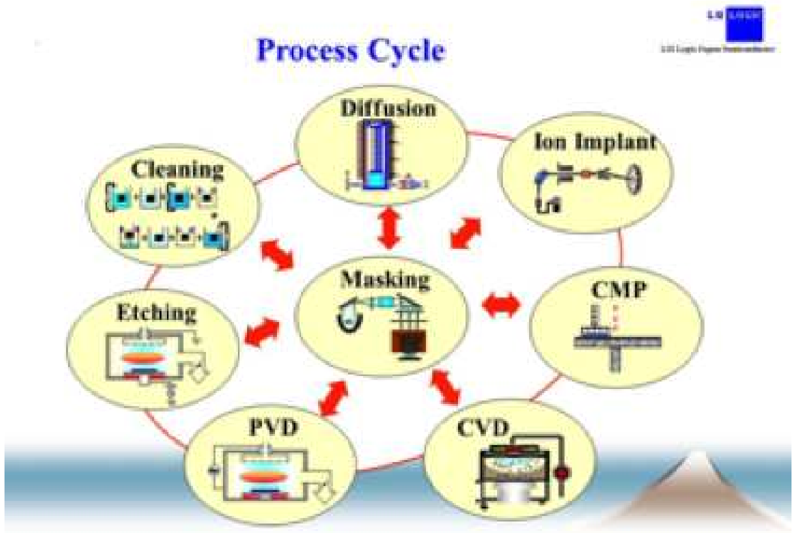
7纳米FinFET逻辑芯片



From Entegris

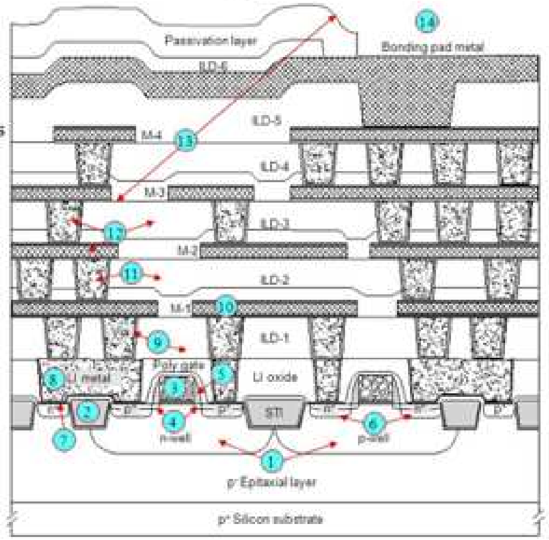
96层3D NAND存储器

Tens of processes, hundreds of materials, and thousands steps to make a ULSI 集成电路的生产流程有十数种工艺、几百种材料、近千个步骤



CMOS Manufacturing Steps

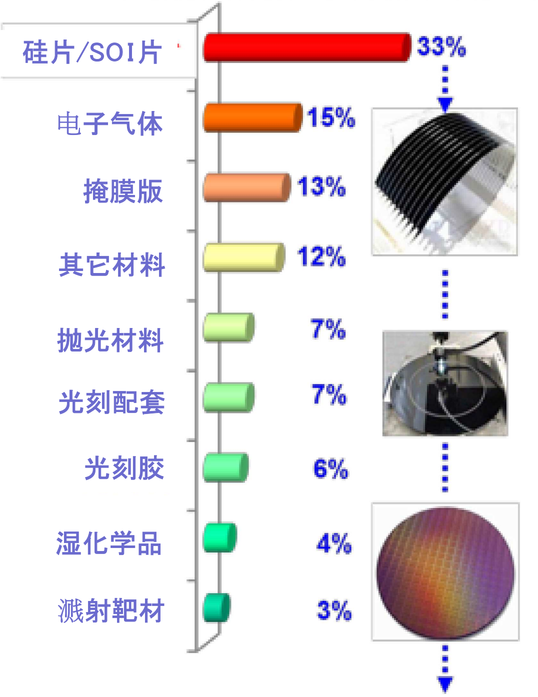
1. Twin-well Implants
2. Shallow Trench Isolation
3. Gate Structure
4. Lightly Doped Drain Implants
5. Sidewall Spacer
6. Source/Drain Implants
7. Contact Formation
8. Local Interconnect
9. Interlayer Dielectric to Via-1
10. First Metal Layer
11. Second ILD to Via-2
12. Second Metal Layer to Via-3
13. Metal-3 to Pad Etch
14. Parametric Testing



Semiconductor Manufacturing Technology
by Michael Quirk and Julian Serda

© 2001 by Prentice Hall

2015年全球集成电路配套材料市场比重



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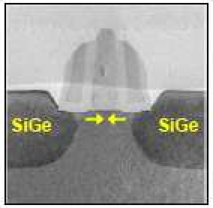
Transistor technologies in the last 15 years is the pinnacle of combined breakthroughs of device-process-materials technologies 过去15年晶体管技术是器件-工艺-材料联合创新的高峰

2003

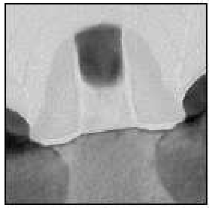
90 nm



Invented
SiGe
Strained Silicon

2005

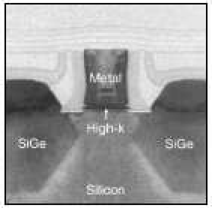
65 nm



2nd Gen.
SiGe
Strained Silicon

2007

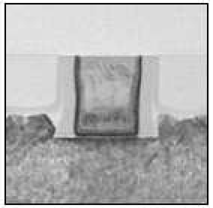
45 nm



Invented
Gate-Last
High-k
Metal Gate

2009

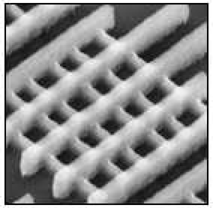
32 nm



2nd Gen.
Gate-Last
High-k
Metal Gate

2011

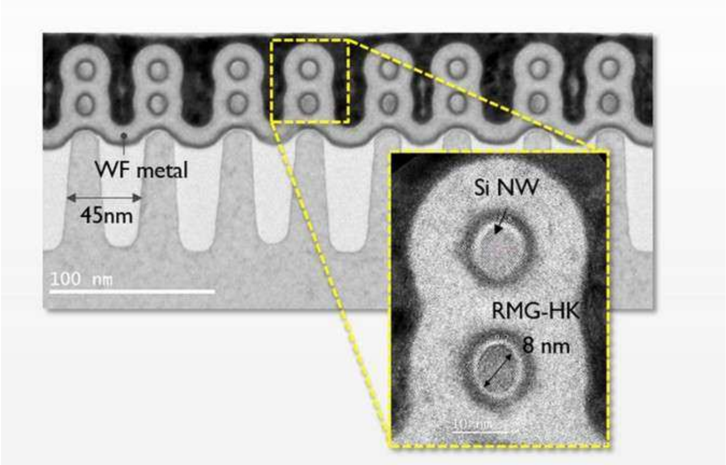
22 nm



First to
Implement
Tri-Gate

Intel, 2011

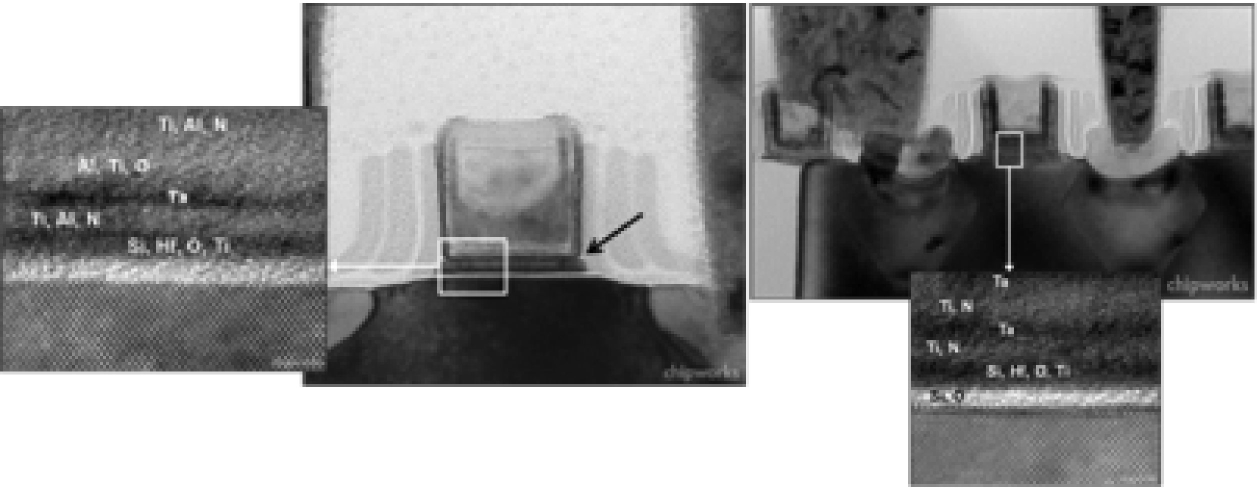
From Intel



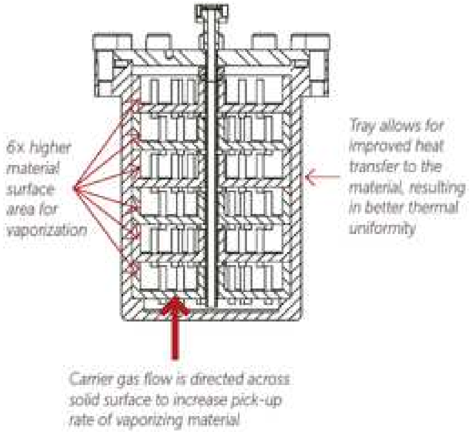
IMEC

Gate-All-Around, 2D materials, the future continues

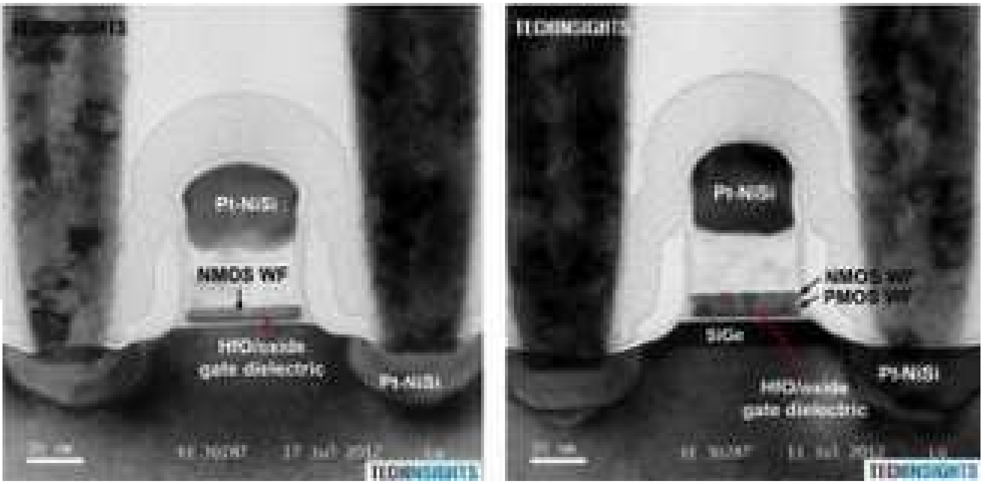
ALD, $HfCl_4$ precursor and solid delivery system are the key to the success of High k/Metal Gate process 原子层沉积、$HfCl_4$前驱体、固体输送系统等技术的结合



45nm replacement gate approach



ATMI’s ProE-Vap
Solid Delivery Syst

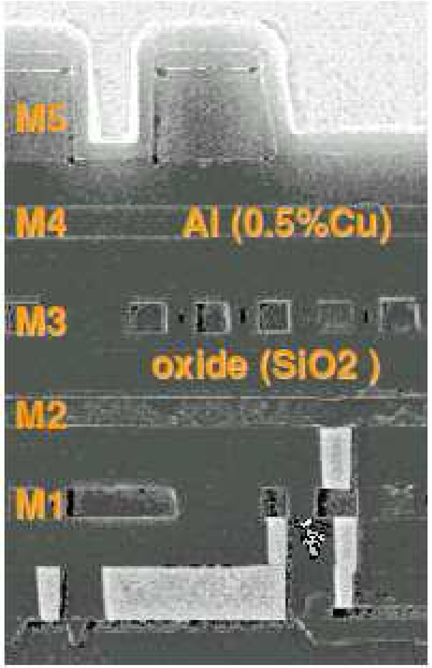


45nm gate first approach

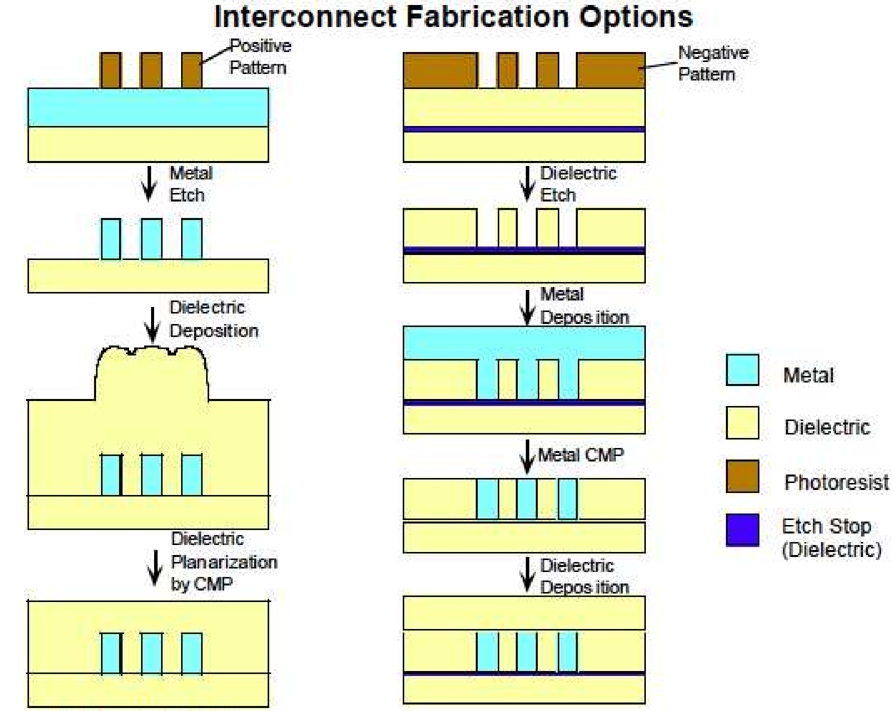
The fruit of Intel-ASM-ATMI collaboration

SITRI

From Al to Cu interconnect, material changed the processes, Co interconnect is already here 从铝互联到铜互联引起金属蚀刻到大马士革工艺流程的改变，从铜互联到钴互联又带来一大批新的工艺材料



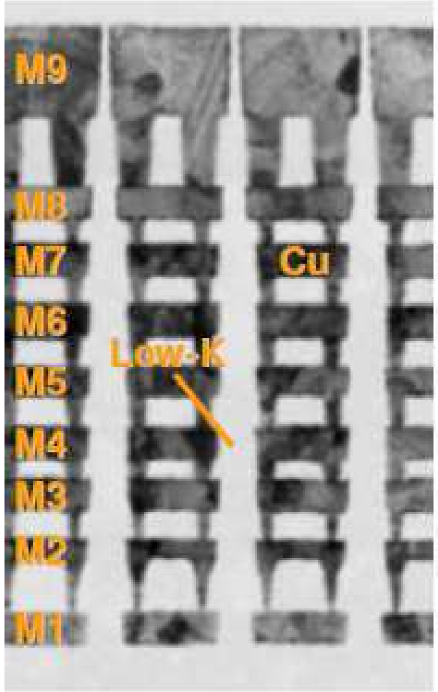
0.25µm Technology
(Motorola, 1996)



Subtractive Etch
(Conventional Approach)

Damascene

Saraswat Stanford EE311 Class Note



90nm Technology
(TSMC, 2002)

New process materials are developed for each new technology node together with processes and integration 每一代技术节点都是工艺——集成——材料的协同发展

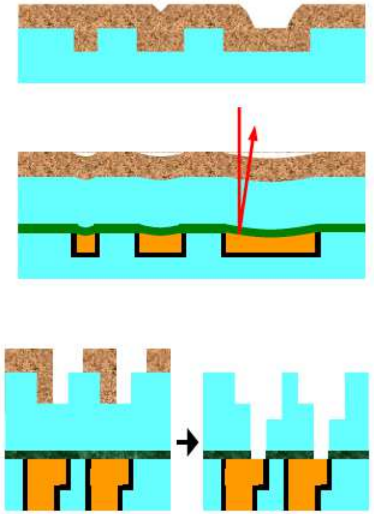
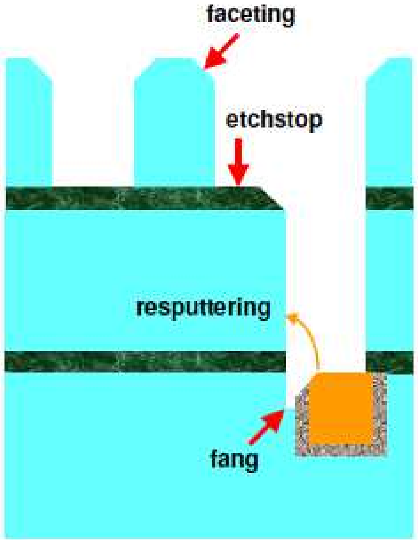
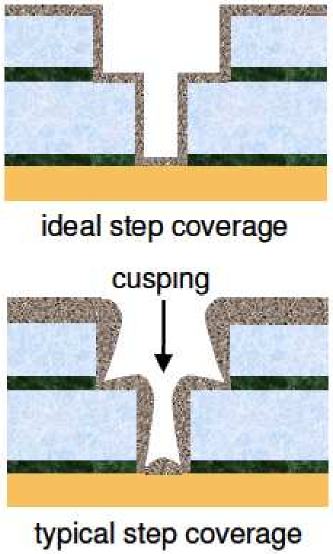


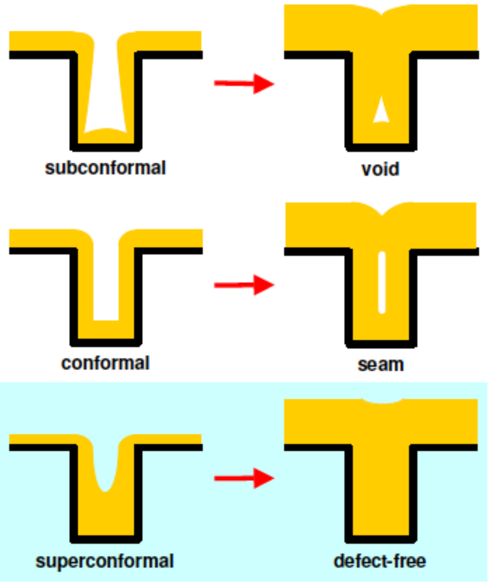
Photo resist



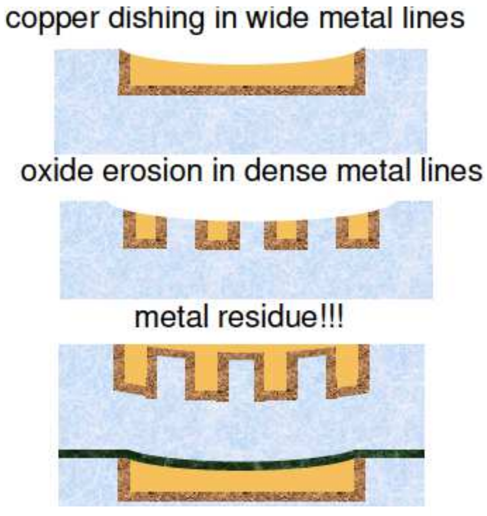
Etch Stop
Post Etch Clean



Barrier (Ta, TaN, Ru, Co)
Seed



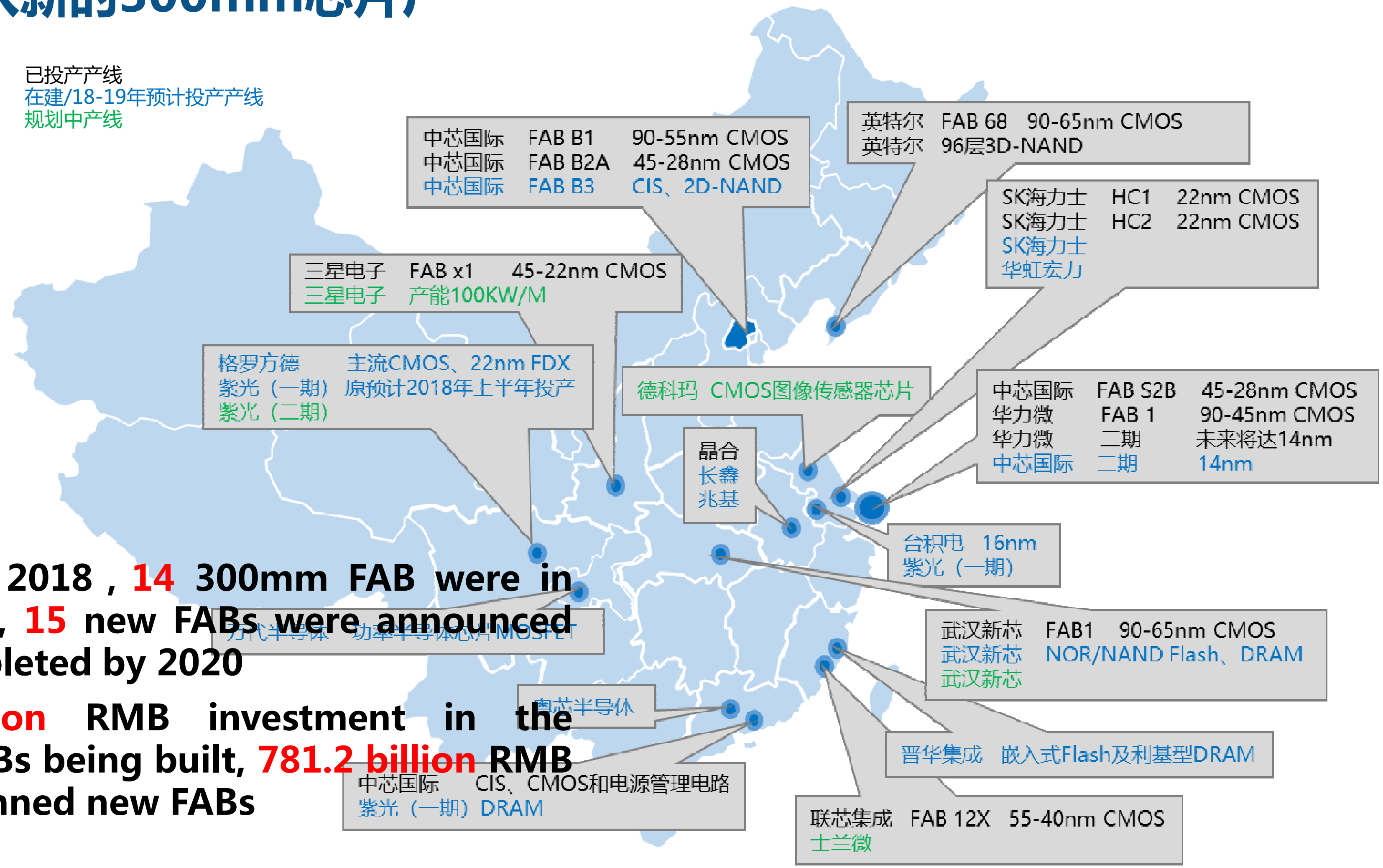
Plating Solution



Loke (Agilent), ISSCS 2003

CMP Slurry
Post CMP Clean

The great leap of Si——Trillion RMB investment in 300mm wafer FABs, a huge market and huge risk 芯片大跃进，1万亿人民币投入新的300mm芯片厂



已投产产线
在建/18-19年预计投产产线
规划中产线

中芯国际 FAB B1 90-55nm CMOS
中芯国际 FAB B2A 45-28nm CMOS
中芯国际 FAB B3 CIS、2D-NAND

英特尔 FAB 68 90-65nm CMOS
英特尔 96层3D-NAND

SK海力士 HC1 22nm CMOS
SK海力士 HC2 22nm CMOS
SK海力士
华虹宏力

三星电子 FAB x1 45-22nm CMOS
三星电子 产能100KW/M

格罗方德 主流CMOS、22nm FDX
紫光（一期） 原预计2018年上半年投产
紫光（二期）

德科玛 CMOS图像传感器芯片

晶合
长鑫
兆基

中芯国际 FAB S2B 45-28nm CMOS
华力微 FAB 1 90-45nm CMOS
华力微 二期 未来将达14nm
中芯国际 二期 14nm

台积电 16nm
紫光（一期）

武汉新芯 FAB1 90-65nm CMOS
武汉新芯 NOR/NAND Flash、DRAM
武汉新芯

万代半导体 功率半导体芯片MOSFET

粤芯半导体

晋华集成 嵌入式Flash及利基型DRAM

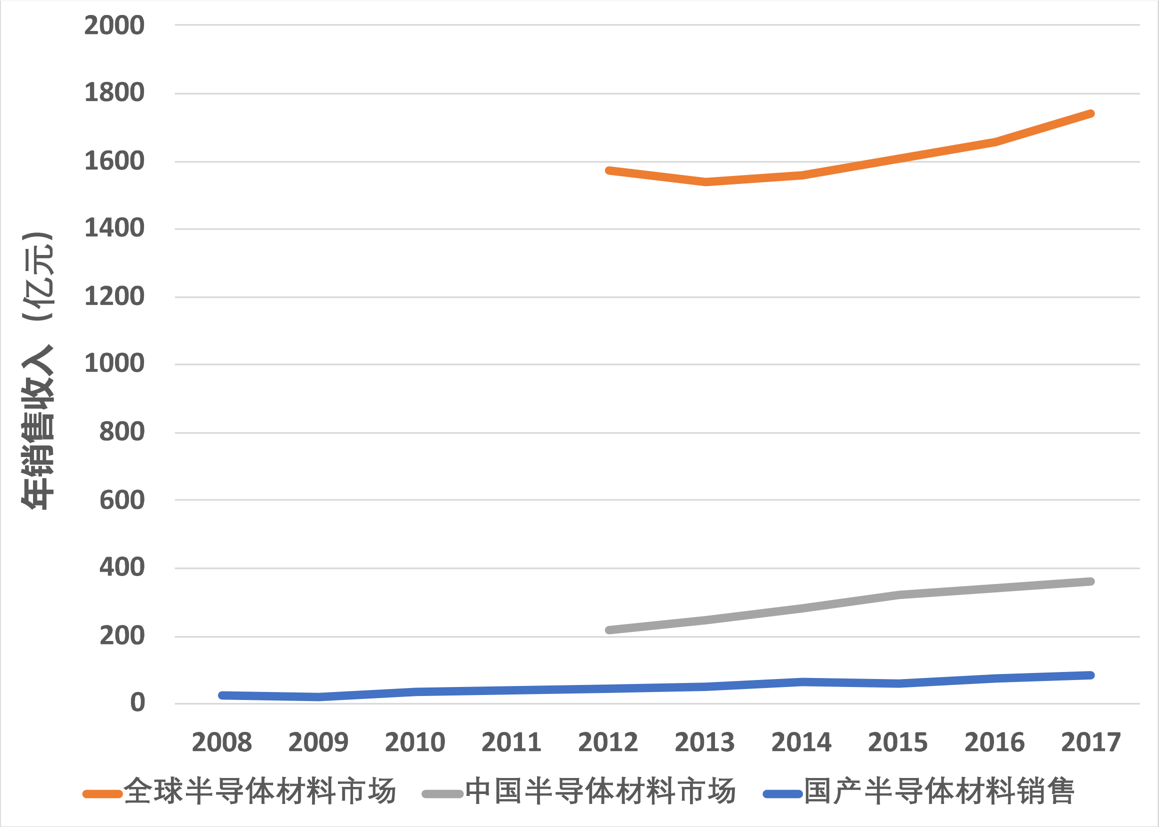
中芯国际 CIS、CMOS和电源管理电路
紫光（一期）DRAM

联芯集成 FAB 12X 55-40nm CMOS
士兰微

- ◆ By end of 2018，**14** 300mm FAB were in production, **15** new FABs were announced to be completed by 2020
- ◆ **501.3 billion** RMB investment in the 300mm FABs being built, **781.2 billion** RMB for the planned new FABs

SITRI

A stronger Chinese IC materials industry is not only the need of national interest, but also the need of a healthy market 中国集成电路材料产业的长足发展不仅仅是国家利益的需要，也是一个健康市场的必然结果

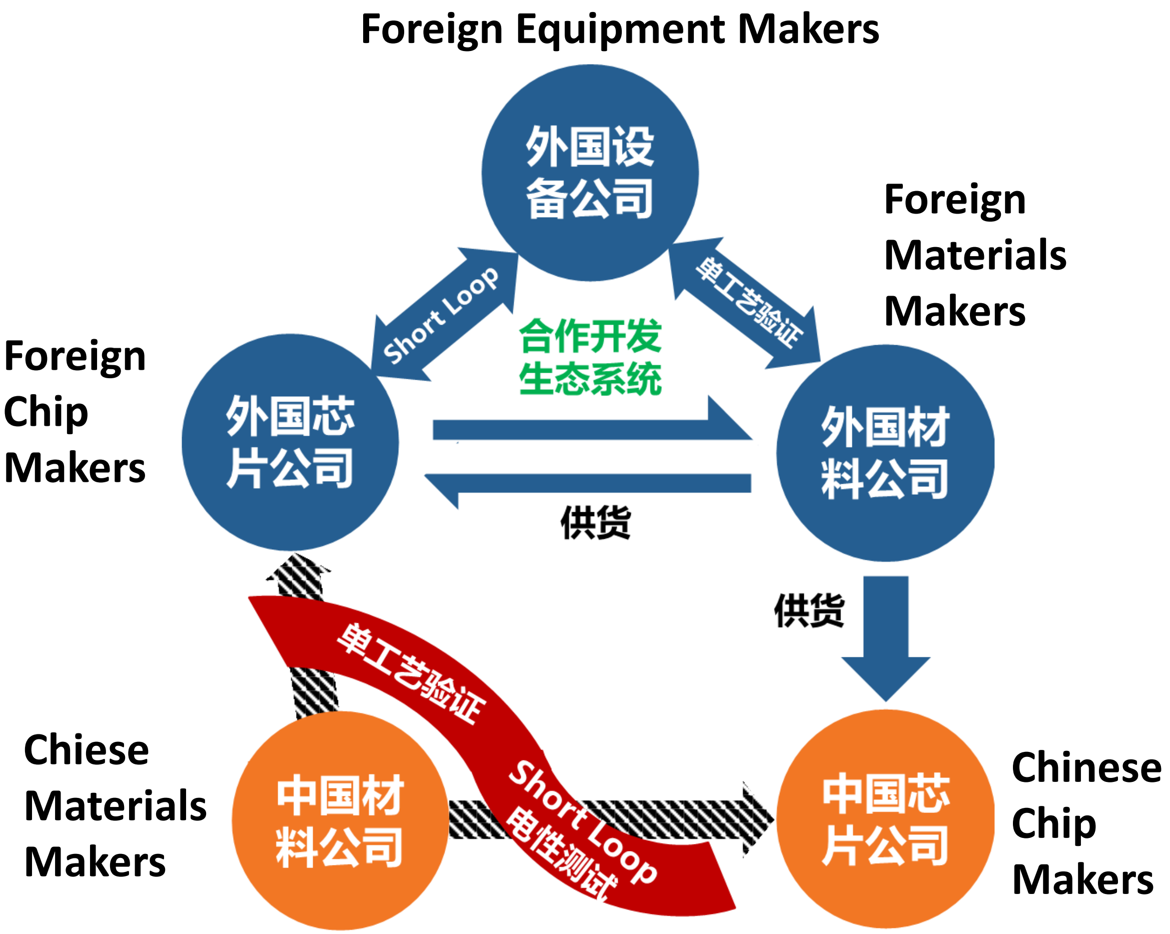


数据来源：集成电路材料和零部件产业技术创新战略联盟2017年报告、SIMIT战略研究室

Collaborations between Chinese materials companies with equipment makers and FABs

Collaborations between Chinese materials companies with Foreign materials companies, equipment makers and FABs

Current collaboration ecosystem works but has its flows 今天的合作生态



Foreign Equipment Makers

外国设备公司

Foreign Materials Makers

外国材料公司

Foreign Chip Makers

外国芯片公司

Short Loop

单工艺验证

合作开发生态系统

供货

供货

Chiese Materials Makers

中国材料公司

Chinese Chip Makers

中国芯片公司

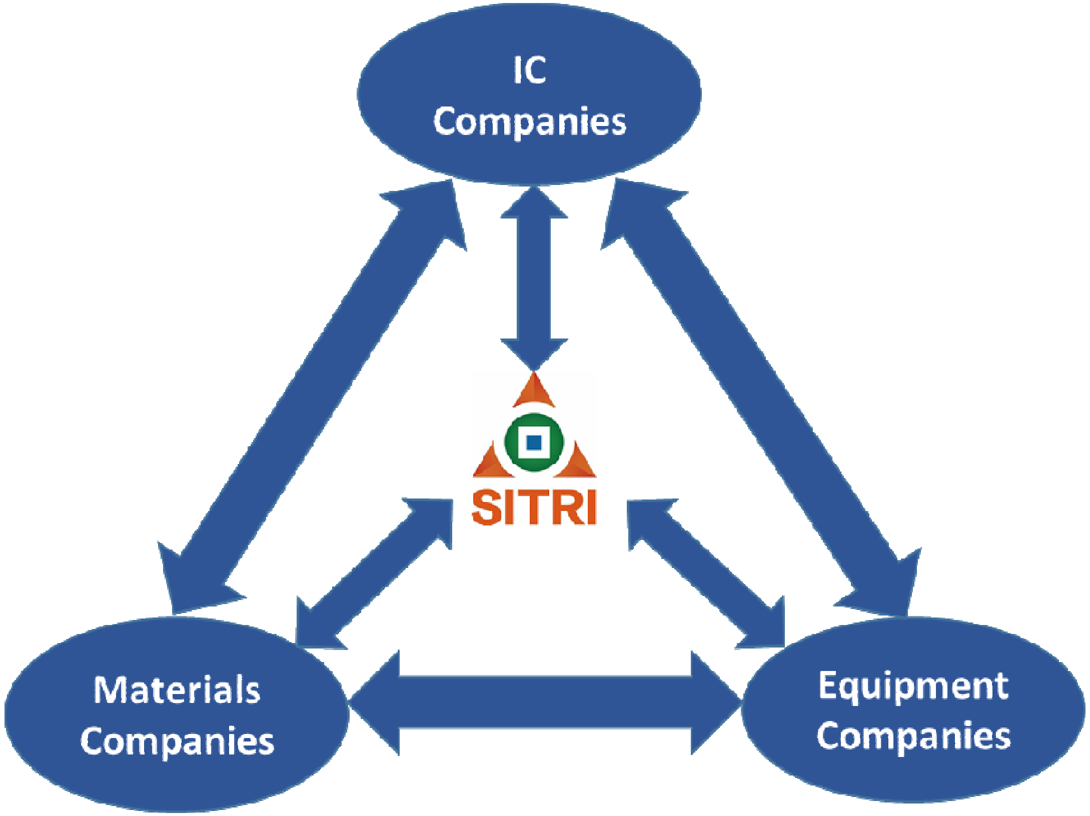
单工艺验证

Short Loop

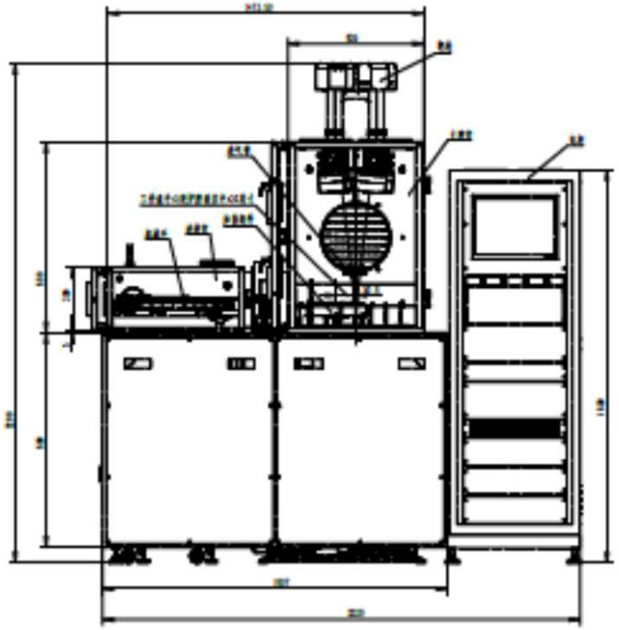
电性测试

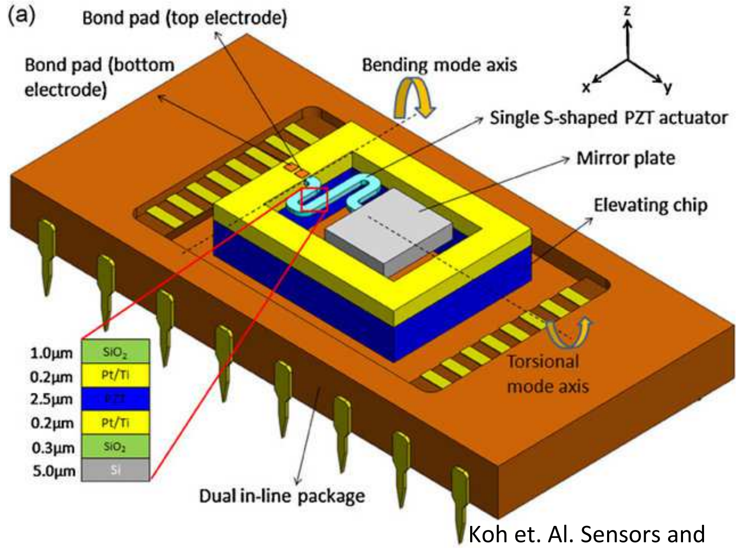
It’s not always fast, not always open or not always straightforward

SITRI willing to help build a better ecosystem 上海微技术工研院愿意帮助建设更好的合作生态

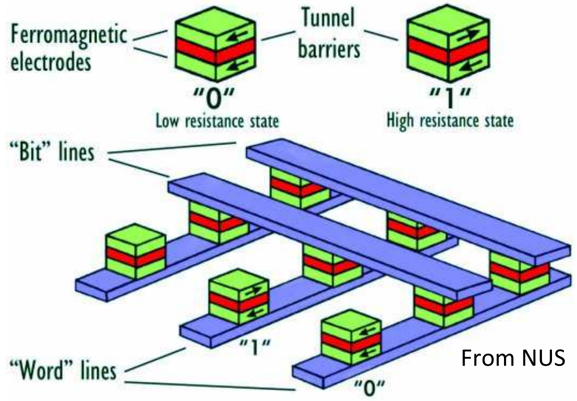


Collaboration on devices-processes-materials may lead to differentiation 器件—工艺—材料的合作也许会带来差异化





Koh et. Al. Sensors and Actuators A 184 (2012) 149–159



From NUS

- Combinatorial PVD
- CVD PZT Thin Film
- V_2O_5 cleaning formulation
- Embedded MRAM or PCRAM

Bring your idea or market to SITRI and make it happen 带着你的主意和市场来入住

SITRI

- 8” MEMS Pilot line
- 8” Si Photonics Pilot line
- Compound Semiconductor Pilot Line
- Process Materials Platform
- Equipment Platform
- Design Service

SIMIT

- XOI Technology
- Phase Change Materials
- Superconductor materials and Systems
- Sensor Systems
- Brain Like Systems

SIMIC HOLDINGS

- Venture Investment
- STT-MRAM

SPTS

SIMGUI

上海新阳
SHANGHAI SINYANG

Conclusion 总结

- Advance in Semiconductor technology depends on collaborative innovations of devices-processes-materials
- Growth of Chinese IC materials industry needs collaborations with materials, equipment and chip makers regardless of region
- These challenges demand closer collaboration
- SITRI spearheads the efforts to usher a new development ecosystem

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