



NANO

Science • Material • Application • Technology

段力

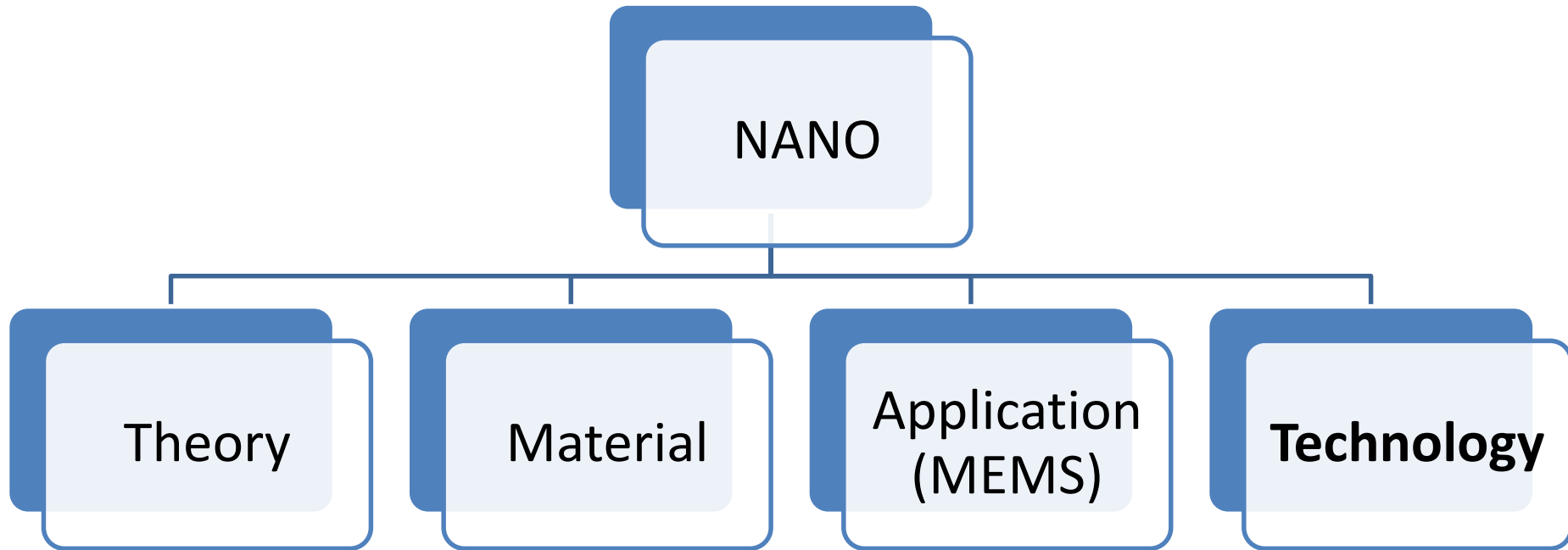
2015.4

Out line

- **NANO** = Science + Material + Application + Technology
- **NANO** – the future



NANO : 1-100nm
NANO: multi-disciplinary
NANO: New world





NANO in a glance

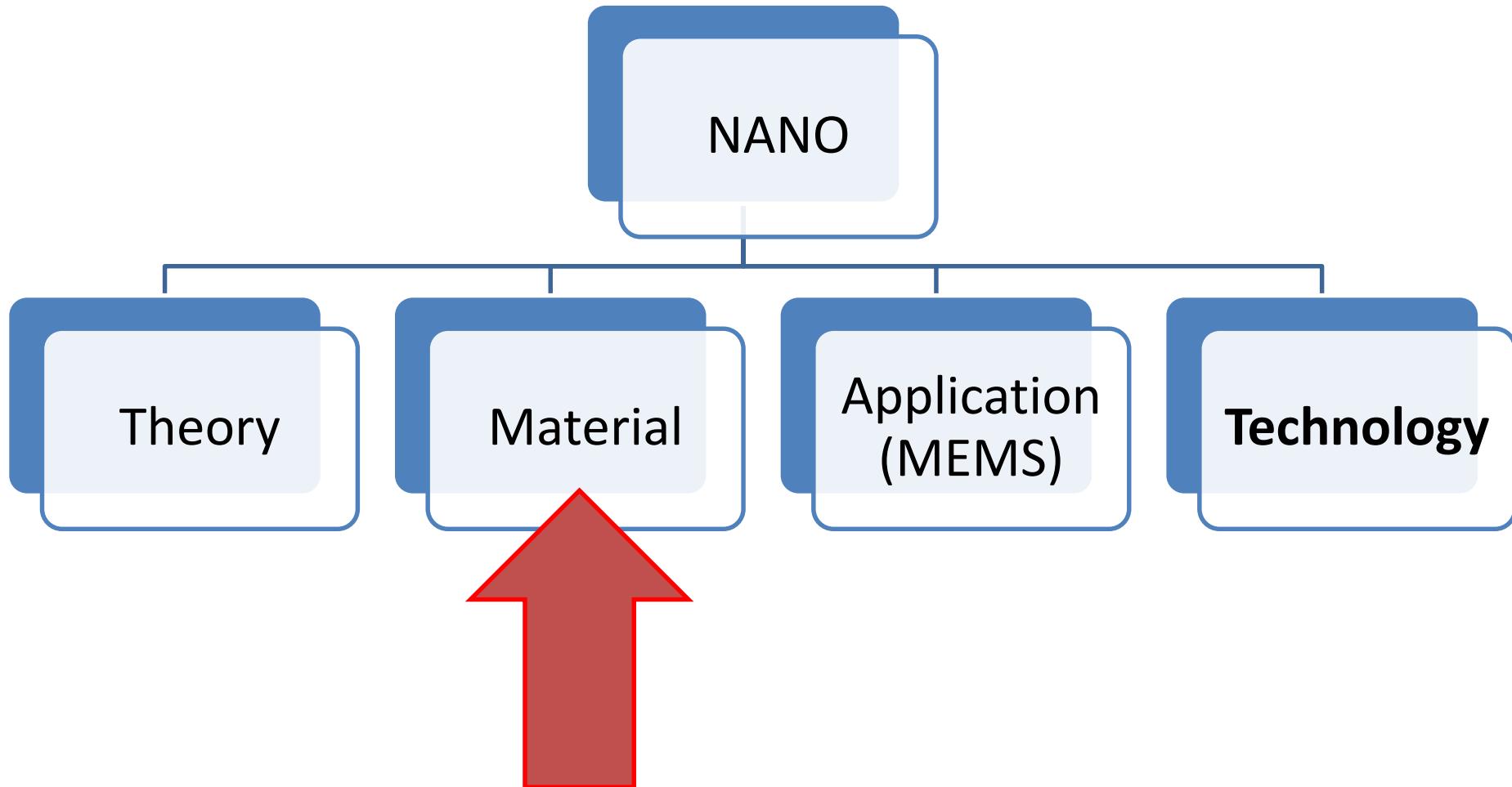
- NANO is:
 - NANO is the study of 1-100 nm range
 - NANO is a multi-disciplinary
 - NANO opens a new world
- 4 main aspects:
 - Science / theory
 - Material
 - Application
 - Technology

NANO: Science

- Multi-discipline
 - Physics + Chemistry + Biology + ... + IC Technology
- Computer simulation:
 - Models: Multi-physics, Poisson equation, Schrodinger equation
 - Application: Quantum structures, 3D, MEMS
 - Tools: COMSOL, *Pisces*, *ATLAS*, *Cadence*



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Nano Material

- 什么是纳米材料？有人简称为0D,1D,2D,3D,也就是至少在一个维度上，尺度在1nm – 0.1mm之间的材料。
- 纳米点、纳米线、薄膜、纳米粉体颗粒\纤维（比表面积大, specific surface area (SSA), 100-1000 m²/g）

NANO: Material

- Nanometer material may have distinct physical / chemical / etc, behaviors, Such as carbon nanotube (CNT), gold, Si/SiO₂ and various hetero junction interface

NANO: Material - thin film

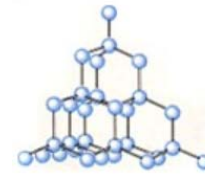
- Most of the devices just use the top layers ($\sim\mu\text{m}$) to fulfill their functions,
- expensive substrate is a waste,
 - 例子。SOI, 镀金的首饰。
- *Thin film technology offers a cheaper way to make use of various expensive bulk materials*
- 薄膜技术： 微电子技术为引进新材料带来可能
 - 硅衬底 + 薄膜： Au, Ti, IIIV, IIVI, 锗, SOI, HKMG, Salicide, Cu , Low K, ...

NANO: Material -酒瓶新酒

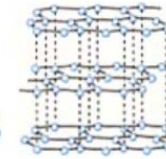
- 同一个元素\不同的视角
 - 门捷列夫与微纳米，同一种原子、分子，不同的组合方式 =》
 - 例如，C材料, 之前只有石墨和金刚石, 现在有了石墨烯和碳纳米管。它们的元素符号都是c。但是由于组合的不同，就形成了新的物质。

Nano: material → C

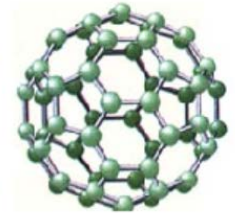
- 金刚石 + 石墨 + 富勒烯 C60,



金刚石

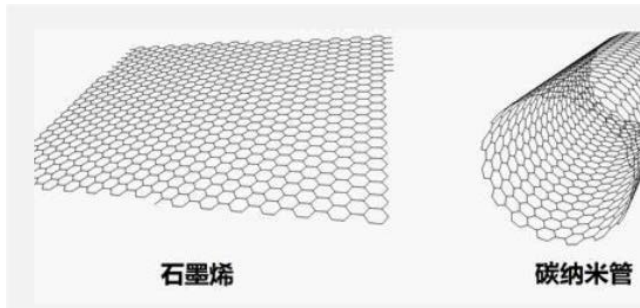


石墨



富勒烯

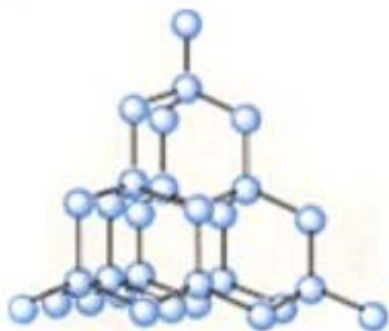
- 石墨烯 + 碳纳米管 (英文 Carbon Nanotube, 缩写 CNT) 日本物理学家 饭岛澄男 (Iijima Sumio)



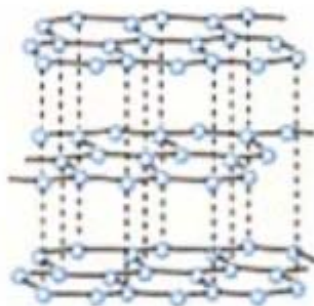
石墨烯

碳纳米管

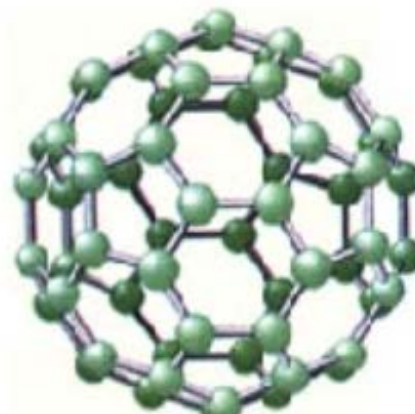
C-石墨烯 (Graphene)



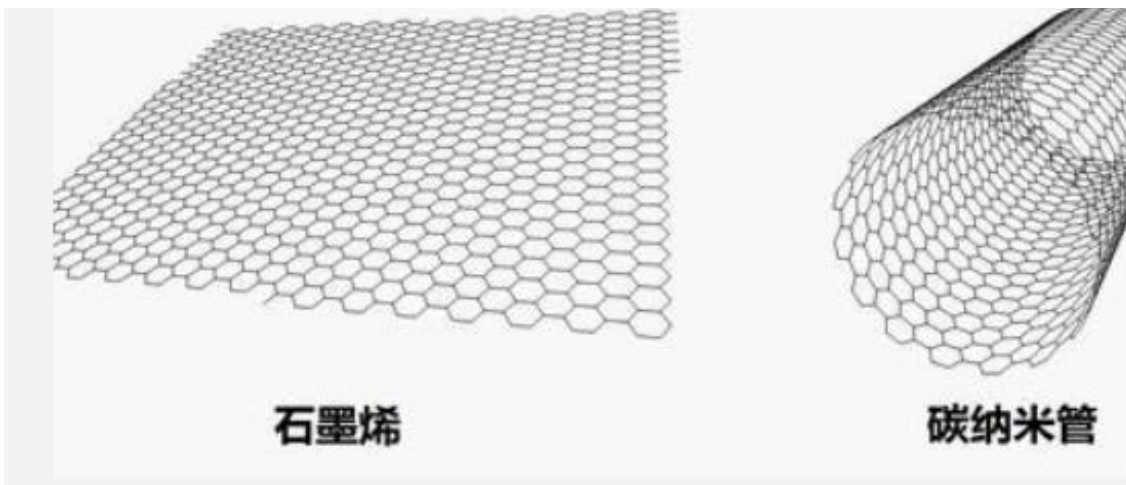
金刚石



石墨



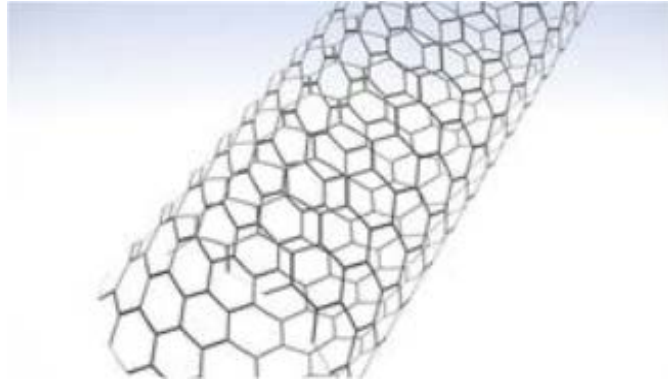
富勒烯



石墨烯

碳纳米管

C- CNT



- 碳纳米管

英文Carbon Nanotube，缩写CNT

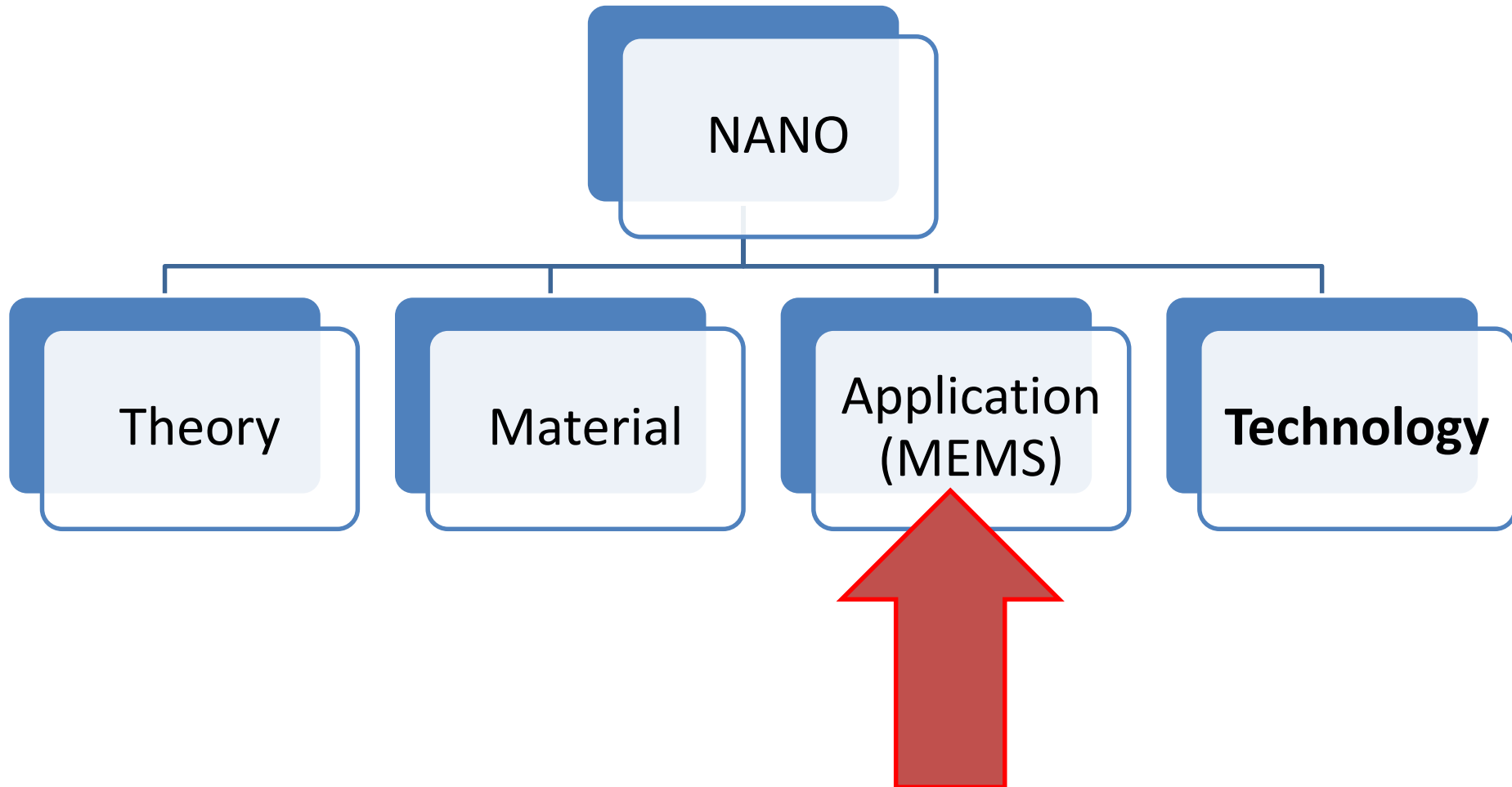
日本物理学家饭岛澄男（Iijima Sumio）

再下边材料就应该是

水



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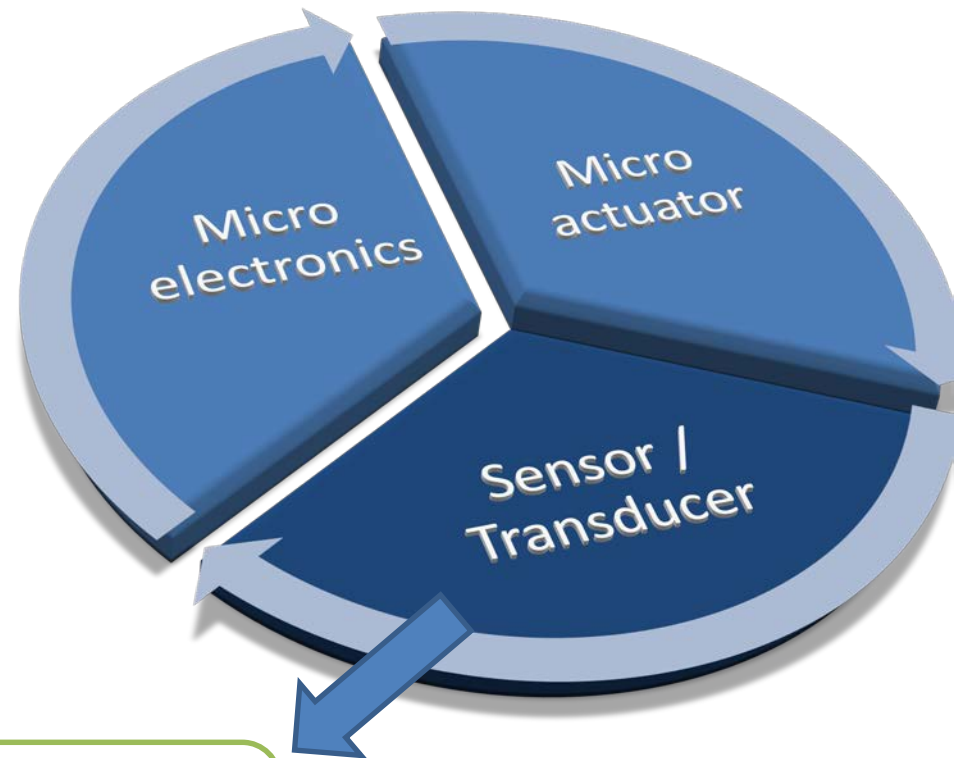


Nano: Applications

- MEMS
 - MEMS (Micro Electro Mechanical System)
 - Sensors, actuators
- New Devices:
 - CNT – man-made material
 - CNT transistors, CNTFET
- Energy, chemistry, civil:
 - Lotus effect – very high water repellence of the leaves of the lotus flower
 - Catalyst
 - Fuel cell
-

Nano: Applications → MEMS

- MEMS / SOC
 - E: IC as a brain, M: as a hand.
 - Sensor is to receive; actuator is to response
 - Technology: borrow the IC technology



【 From/to 】 Temperature, optical, mechanical, chemical, magnetic signals

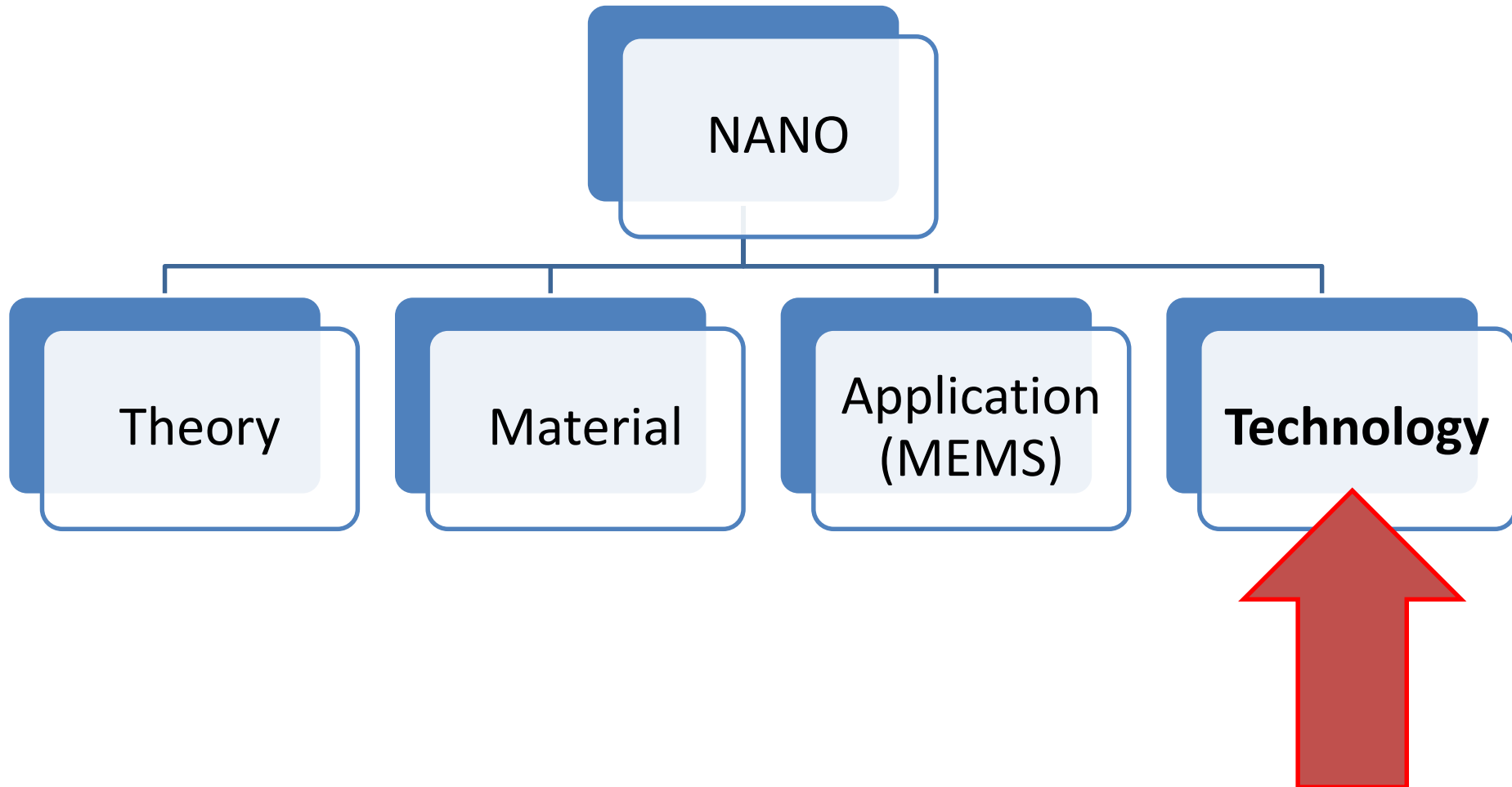
【 To/from 】 An electrical signal

Nano: Applications → 出淤泥而不染

- [周敦颐](#) 《爱莲说》 「莲花出淤泥而不染」
为什么呢？
- Lotus Effect 莲之所以出淤泥而不染的原因是莲叶的表面奈米结构达到自洁的效果，如此表面自我洁净的物理现象称为『莲叶效应』！
- [科学家](#)们模拟莲叶的表面，发明了纳米自清洁的衣料和建筑涂料，只需一点水形成水滴，就可以自动清洁衣物和建筑表面。



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Nano Technology

- Most from IC industry
- 4 basic steps (repeating)
 - Draw
 - Add
 - Remove
 - Modify



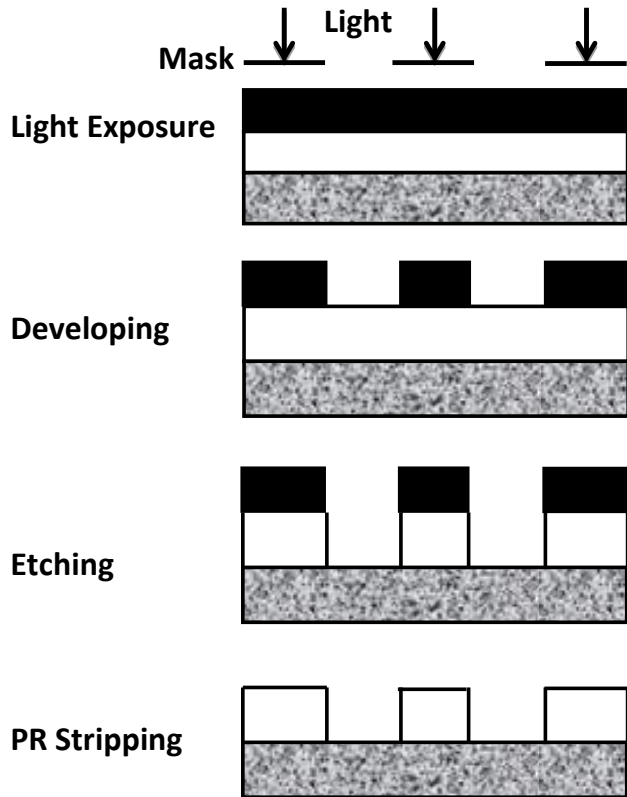
Nano Technology

- Draw – using photolithography to draw a pattern of pictures
 - Light, exposing
 - Mask, patterning
- Paint – using the pattern to add, remove or change the material selectively
 - Add: thin film deposition, epitaxy, thermal growth,
 - Remove: wet etching, plasma etching, CMP
 - Modify: ion implantation, alloying, saliciding

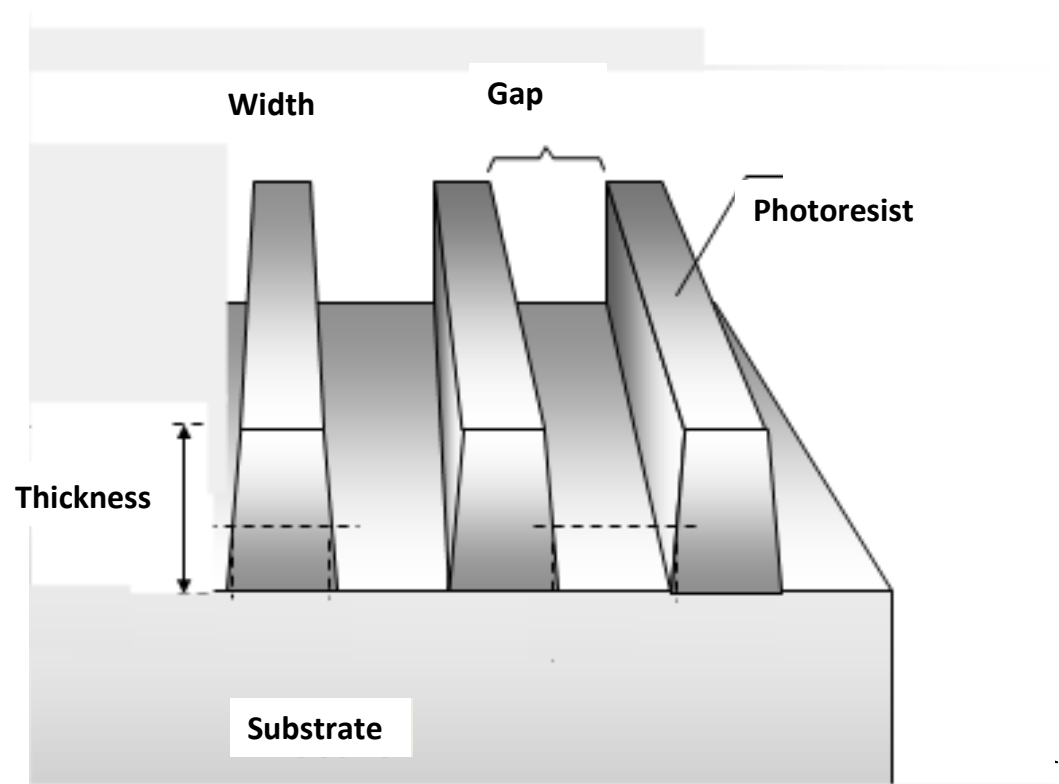
Micro/nano process

- 在薄膜淀积之后，
- 在表面涂一层光刻胶（PR），
然后光线（Light）透过光刻版（Mask）对硅片进行曝光（Light Exposure）、
显影（Developing）、
烘干(Baking)
- 之后进行刻蚀（Etching），
- 除去光刻胶之后，就在薄膜上得到了所需要的图案

Micro/nano process

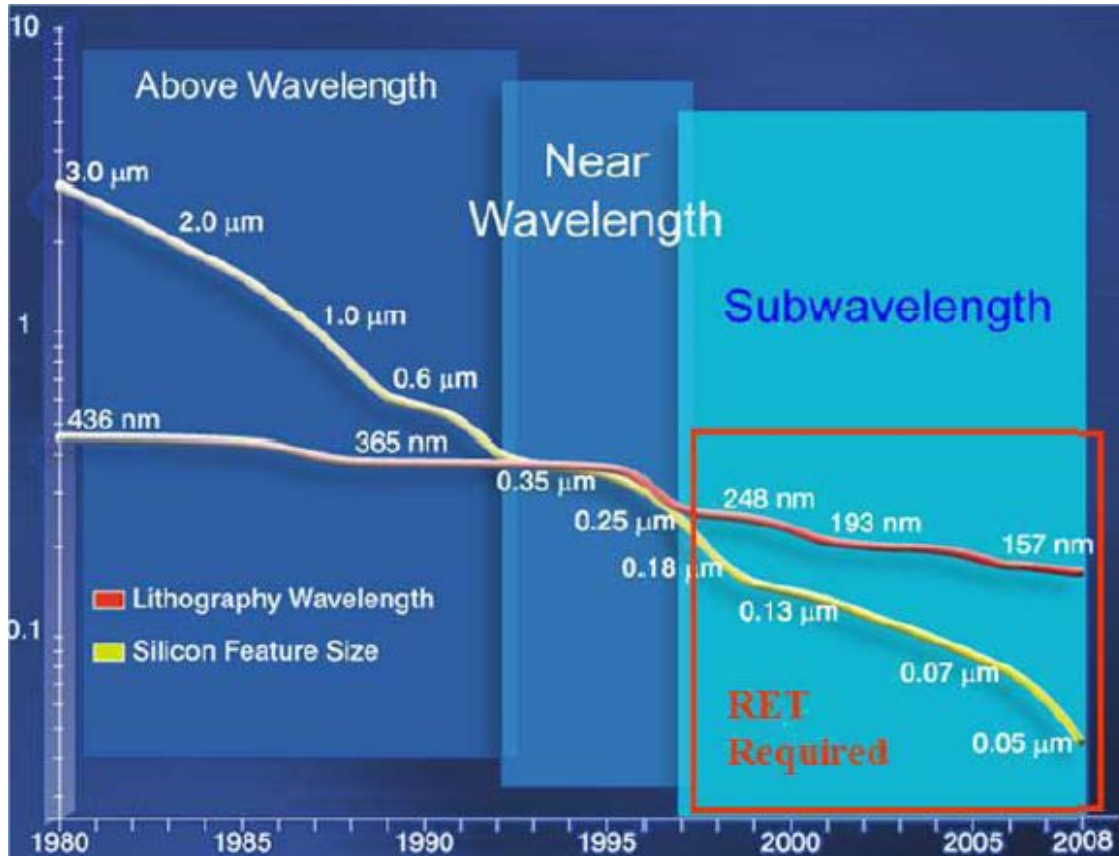


(a)



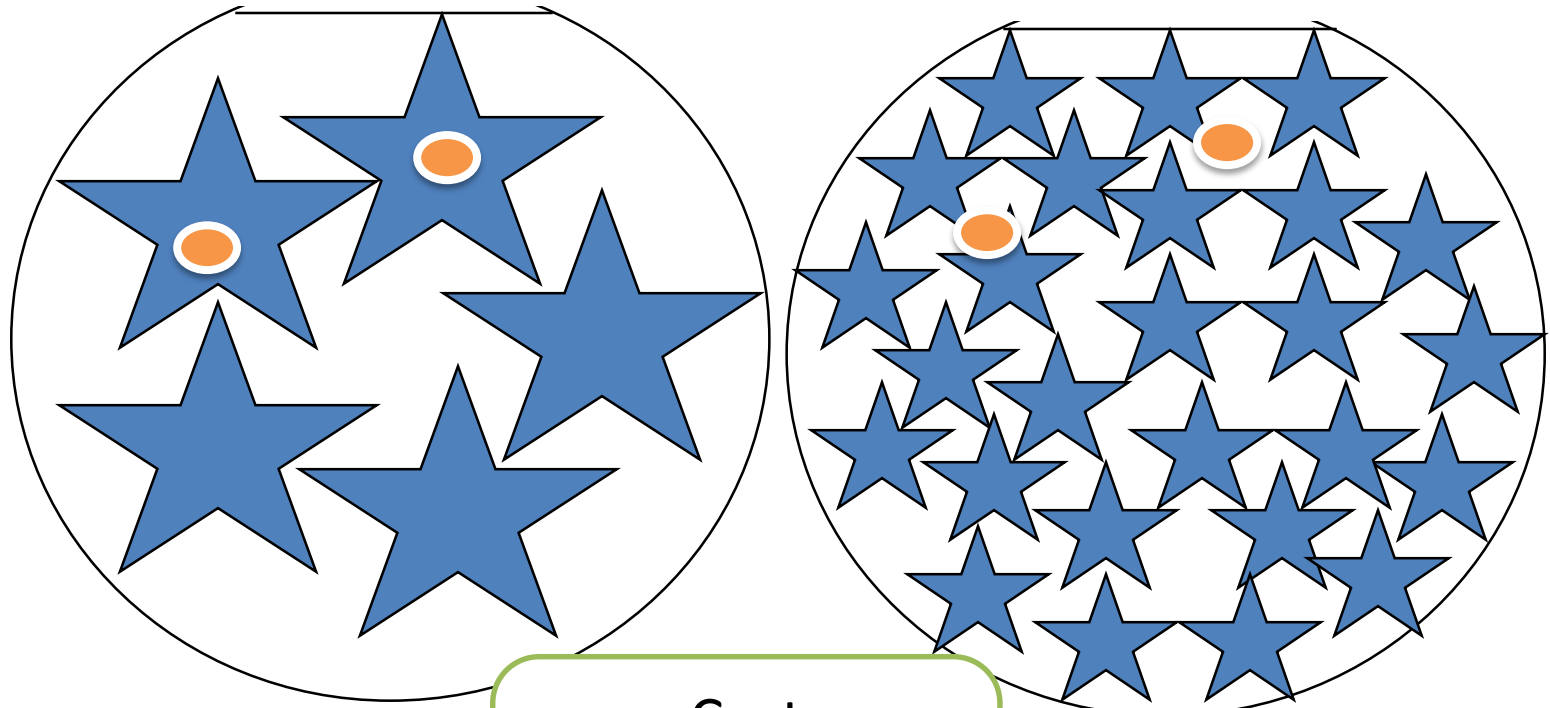
(b)

Nano Technology: Photolithography



Reducing the size for the past 30 years

Reducing the size , why?

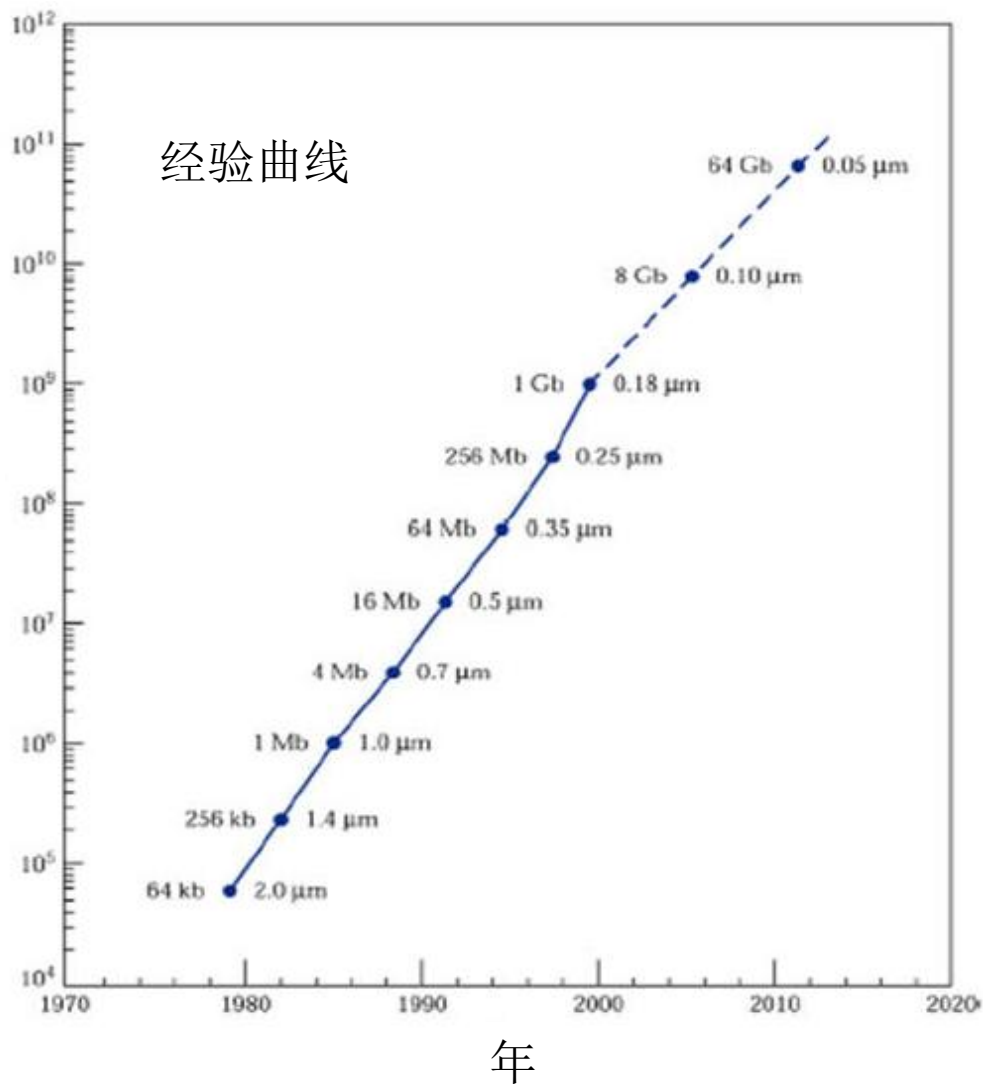


Cost
Yield
More function



摩尔定律-集成电路技术发展进度法则

MOSFET 的数量



- MOSFET 的数量和年呈指数增长
 - ✓ 1millionX / 30yrs • 2X / month • 64K-64G
 - ✓ K:10³, M:10⁶, G:10⁹
- MOSFET, 2 μm – 0.050 μm , 等比例定律, Scaling Down Rule

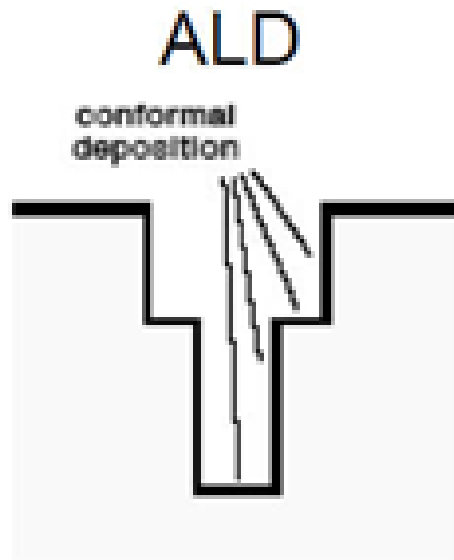


Nano Technology: Thin film deposition

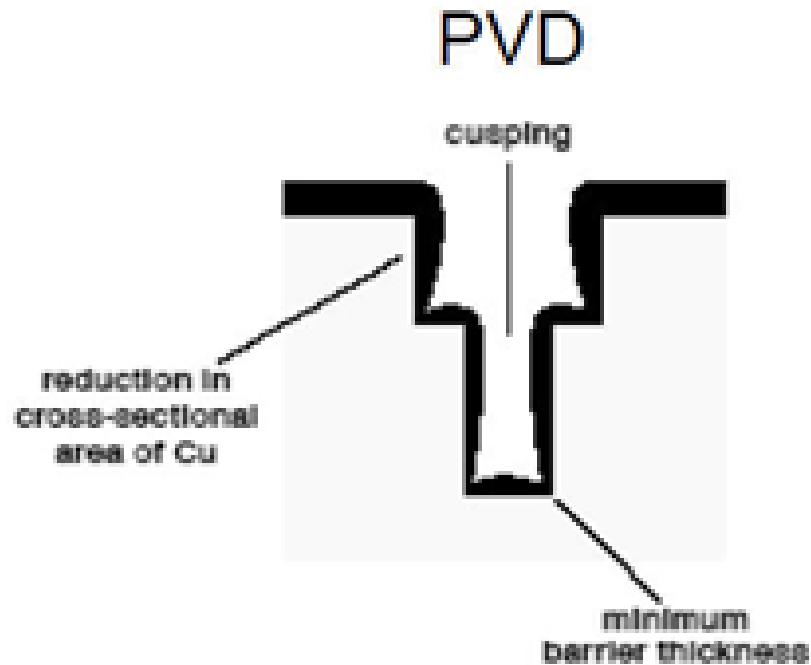
- Methods:
 - PVD, CVD
 - Epitaxy
 - Thermal
- Criteria:
 - Uniformity, quality, defects, step coverage, deposition rate
- Materials:
 - Base material, Si
 - Optical (LED, Solar) ,Magnetic (Compass), Stress (Strained Si)

ALD: delicate thin film growth

Better thickness control

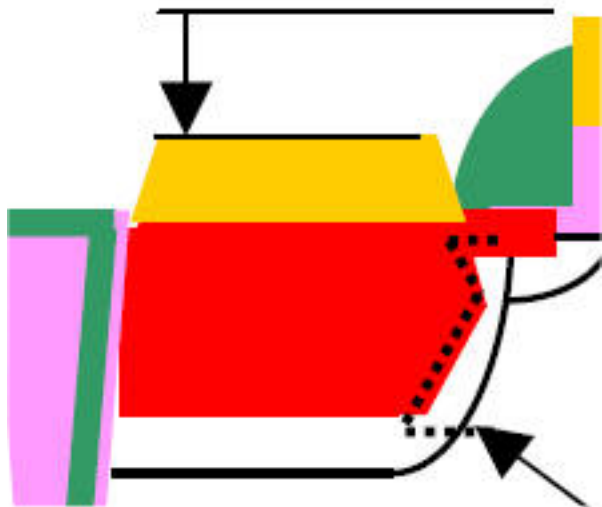


Better 3D coverage



Nano Technology: etching

- 【Wet etching】 easy, hard to control lateral
- 【Dry etching】 ion + chemical, < 0.1um patterning
- 【Damascene】 CMP, hard to etch Cu, Metal Gate
- 【3D Shaping】 Σ shape patterning, SiGe



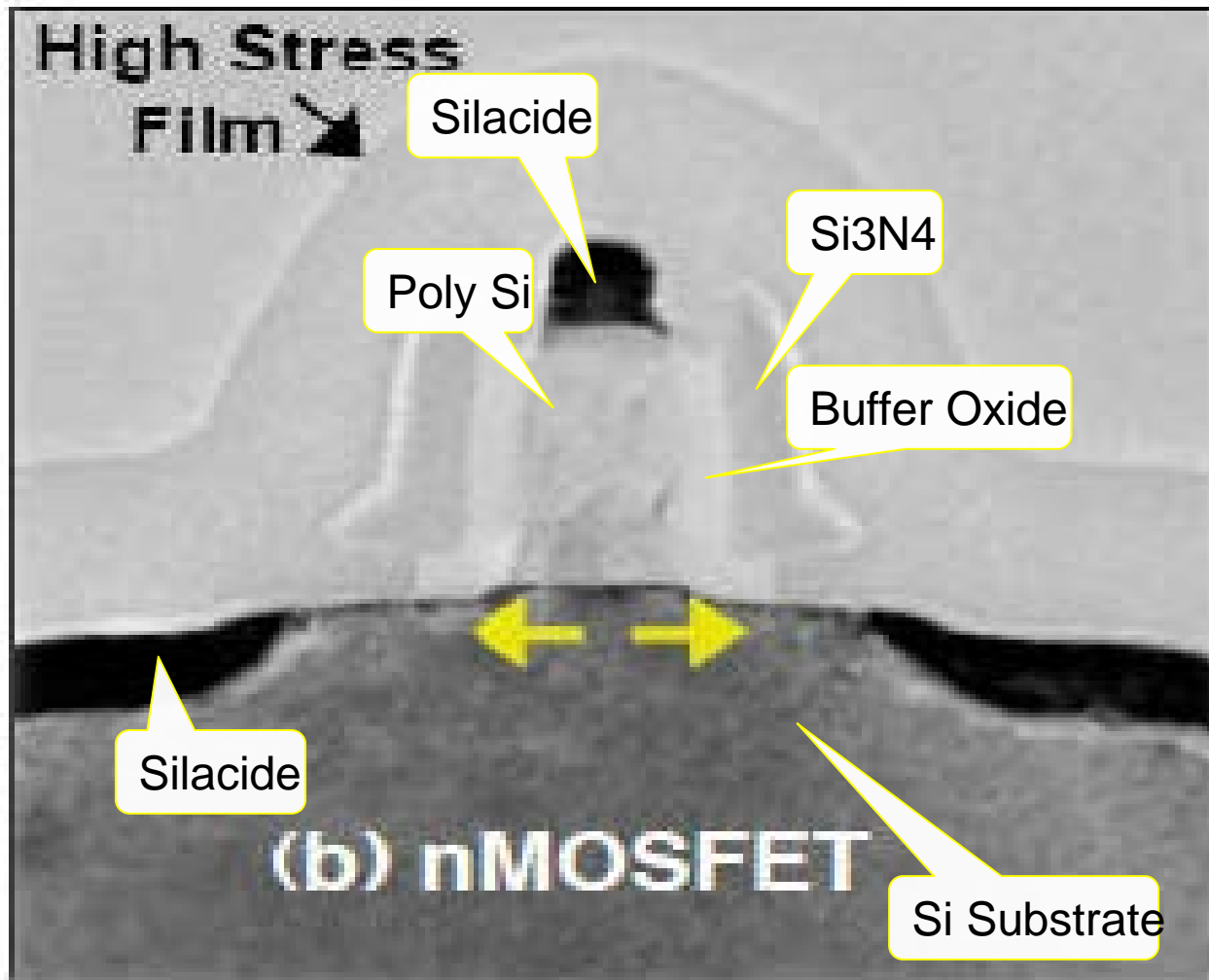
*isotropic vs. anisotropic,
{111} < {110} < {100},
selectivity,
etch rate,*



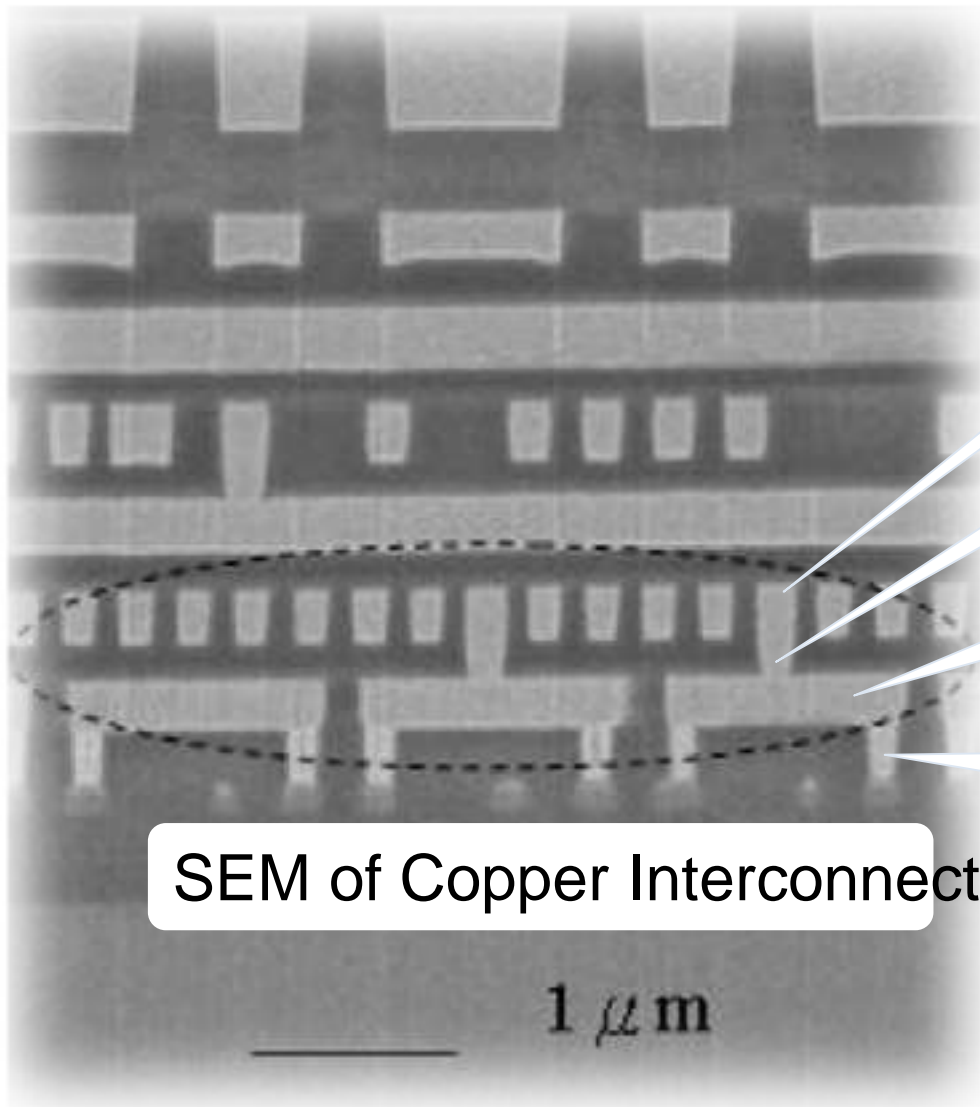
Nano Technology: modify the material

- Ion implantation, annealing
- Salicide, sputtering, alloying
- Post processing
 - FPGA
 - Flash
 - ROM, Fuse, anti-fuse

FEOL: smaller and smaller “T”s



BEOL more and more "L"s

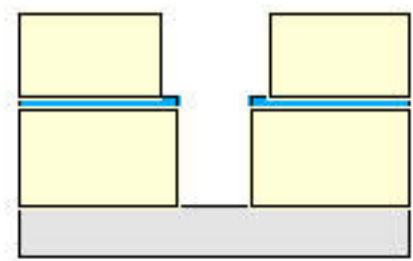


M2

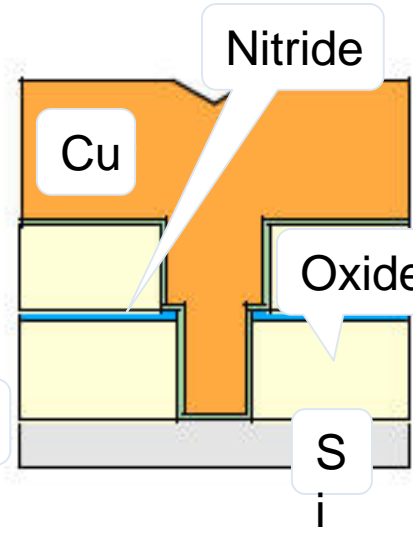
Via

M1

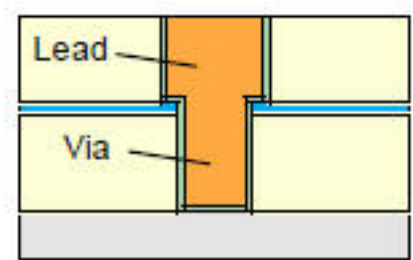
Contact



ILD
淀积/
刻沟



Cu
淀积



CMP
磨平

Out line

- NANO = Science + Material + Application + Technology
- NANO - future trend



Nano trend

- **Longer: 长度方向: 科研**
 - 新的纳米材料 (0D、1D、2D), 人造材料
 - 新的纳米物理、原理
 - 新的纳米器件、新纳米结构
 - MEMS
- **Wider: 宽度方向: 应用**
 - 利用现有的微纳技术进行跨学科的应用

Longer: physics

- 新材料
 - 启发，用最便宜的材料，做成最不平凡的事，就是使用自然界常用、便宜的材料，来造成革命性的变革。
 1. 首先是Si，就是沙子，造成了现在的信息革命。
 2. 然后是C，就是木头。碳：金刚石+石墨+C60+graphene+CNT，同一种原子、分子，不同的组合方式 =》新的材料，旧瓶装新酒。
 3. 然后是 H₂O，水里面的内容是很很多的，不仅包含了物质层次，也包含了意识层次。
- 新器件、新原理
- 新结构、MEMS

Wider: 应用

这张图是2006年时候的图。那个时候图里面的这些东西还都是分立的元件。现在，他们都被集成了，就是现在我们的智能手机。

The slide, titled "Importance of Form Factor", displays six distinct electronic devices arranged in a grid. At the top center is a "STAR TREK COMMUNICATOR" (a gold and silver handheld device). To its left is a "GPS Hand-Held Receiver" (a blue handheld device with a screen). To its right is a "Cell phone" (a silver flip phone). Below the communicator is a purple "MP3 player" (a handheld device with a screen and buttons). Below the GPS receiver is a "PDA" (a handheld device with a screen and a stylus). Below the MP3 player is a "Digital Camera" (a silver digital camera). The slide also features a logo for "Saraswat Stanford University" in the bottom left corner and the text "EE311/Interconnect" in the bottom right corner. The slide is presented within a window that has a Windows taskbar at the bottom with several open applications.

基本思路，科技人人白日梦。

也就是将自己的所长、技术与经历用于要用的领域。



Summary

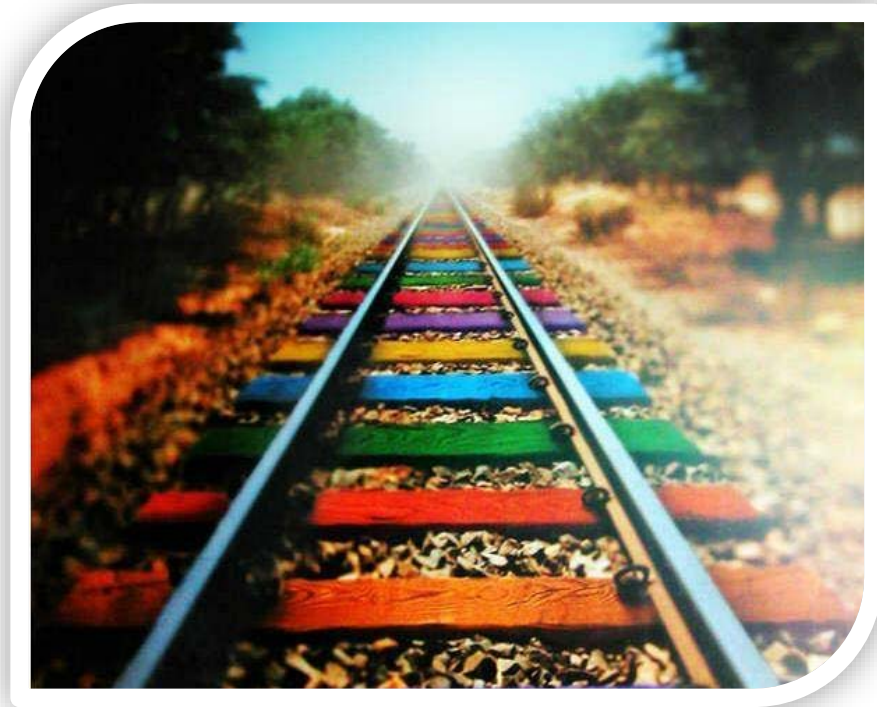
- Nano is a multidisciplinary of Physics + Chemistry + Biology + nano Engineering
- Nano has 4 main aspects: Science, Material, Application and Technology
- 3 main nanotechnologies : photolithography, etching, and thin film, in the playground of nano/MEMS fabrication.
- MEMS + SOC may offer a large application and market place to play.

习题

- Nano的4个方面？
- Nano 跨学科？几个学科？
- Nano Technology 的4个基本工艺？
- “加法的”几种方法？
- “减法的”几种方法？
- Micro/nano process 的示意图？
- 缩减光刻尺寸对微纳工艺集成电路发展的三项基本贡献？
- 微纳学的未来发展的两种方向？



FIN



Thank you!