Principles of Micro- and Nanofabrication for Electronic and Photonic Devices

Film Deposition
Part VI: Wet Process

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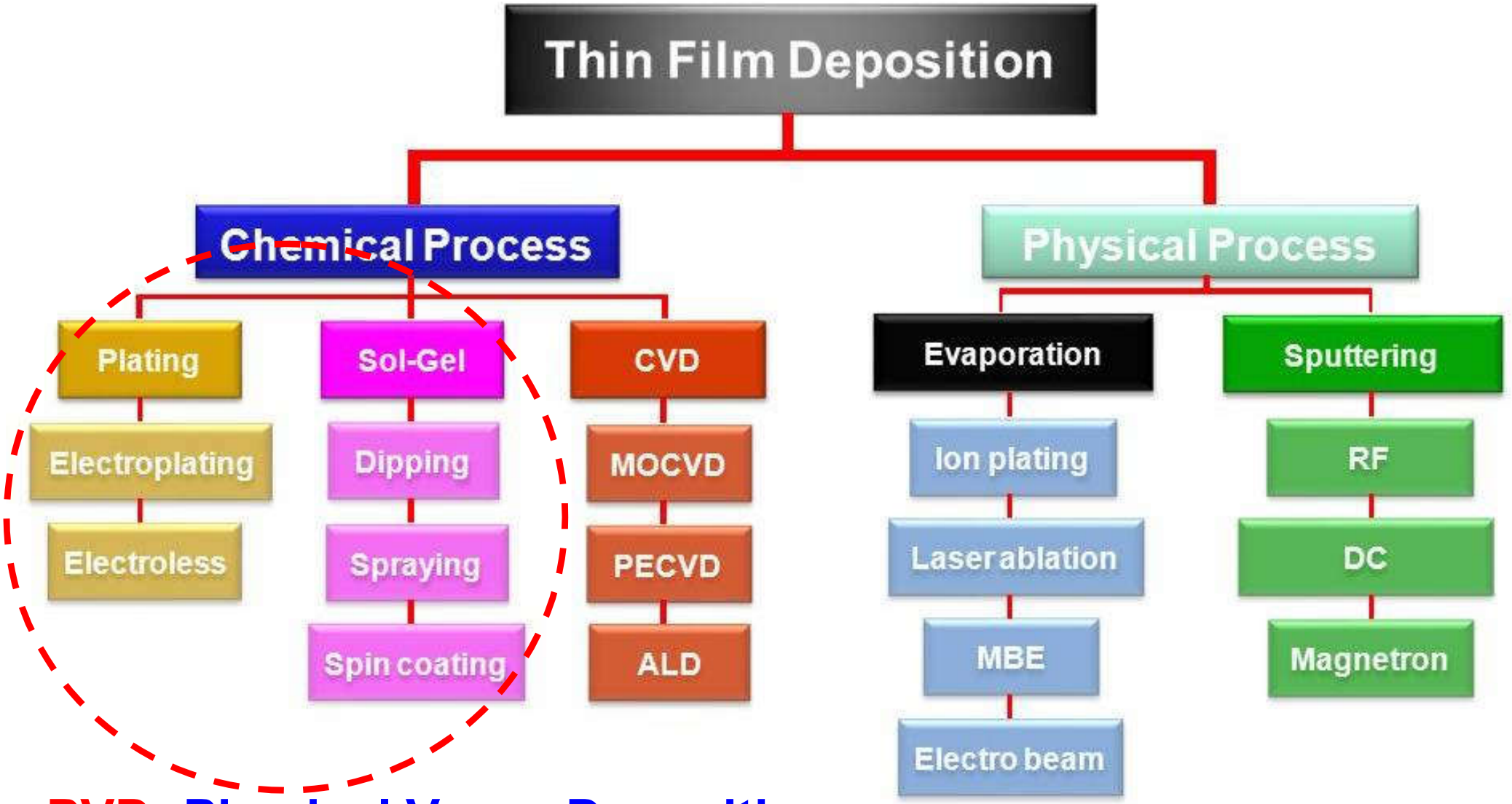
Film Deposition

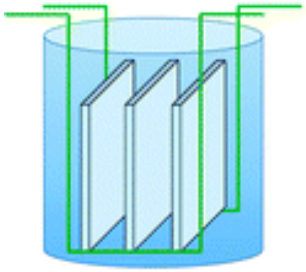


PVD: Physical Vapor Deposition

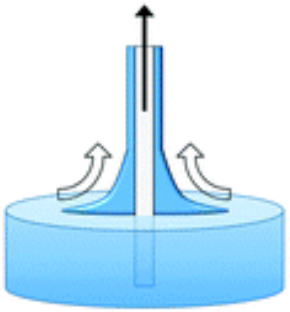
CVD: Chemical Vapor Deposition → **'dry' process**

Solution based Deposition

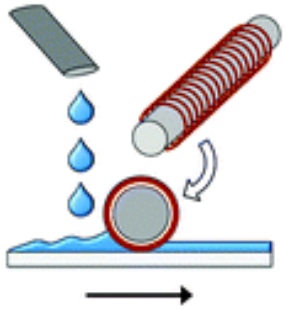
'wet' process

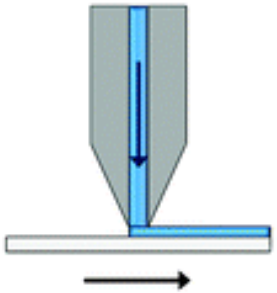

Chemical Bath

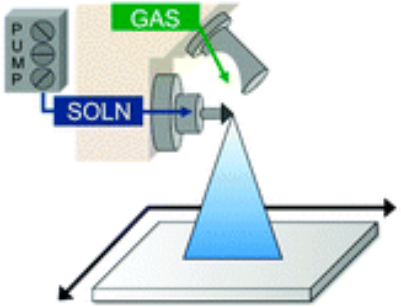

Spin-coating


Dip-coating

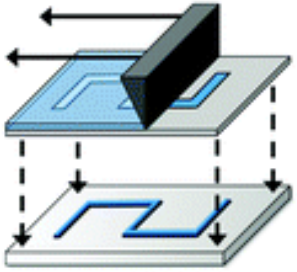

Doctor Blade

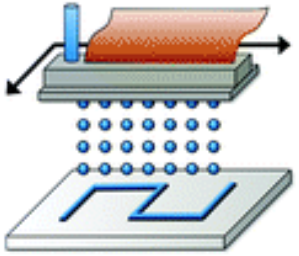

Metering Rod

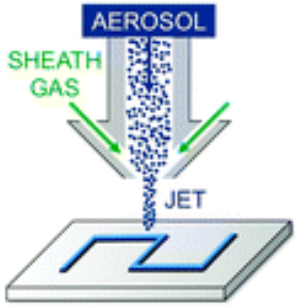

Slot-casting



Spray-coating


Screen Printing


Inkjet Printing

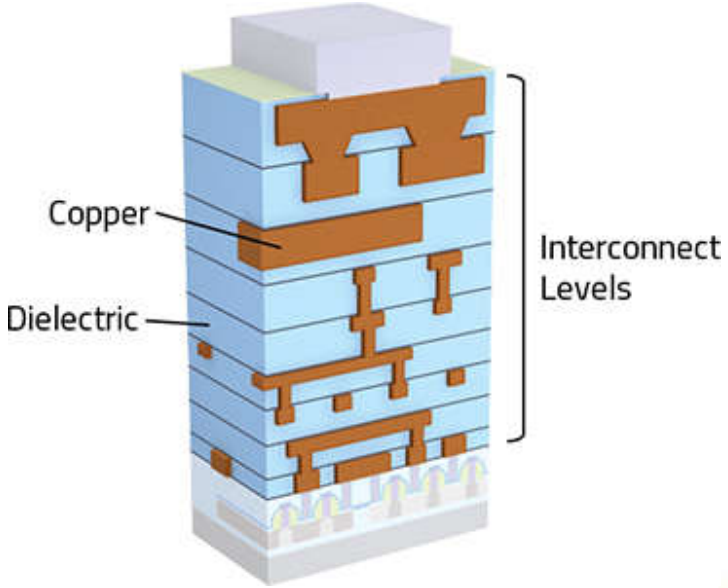


Aerosol Jet

Examples

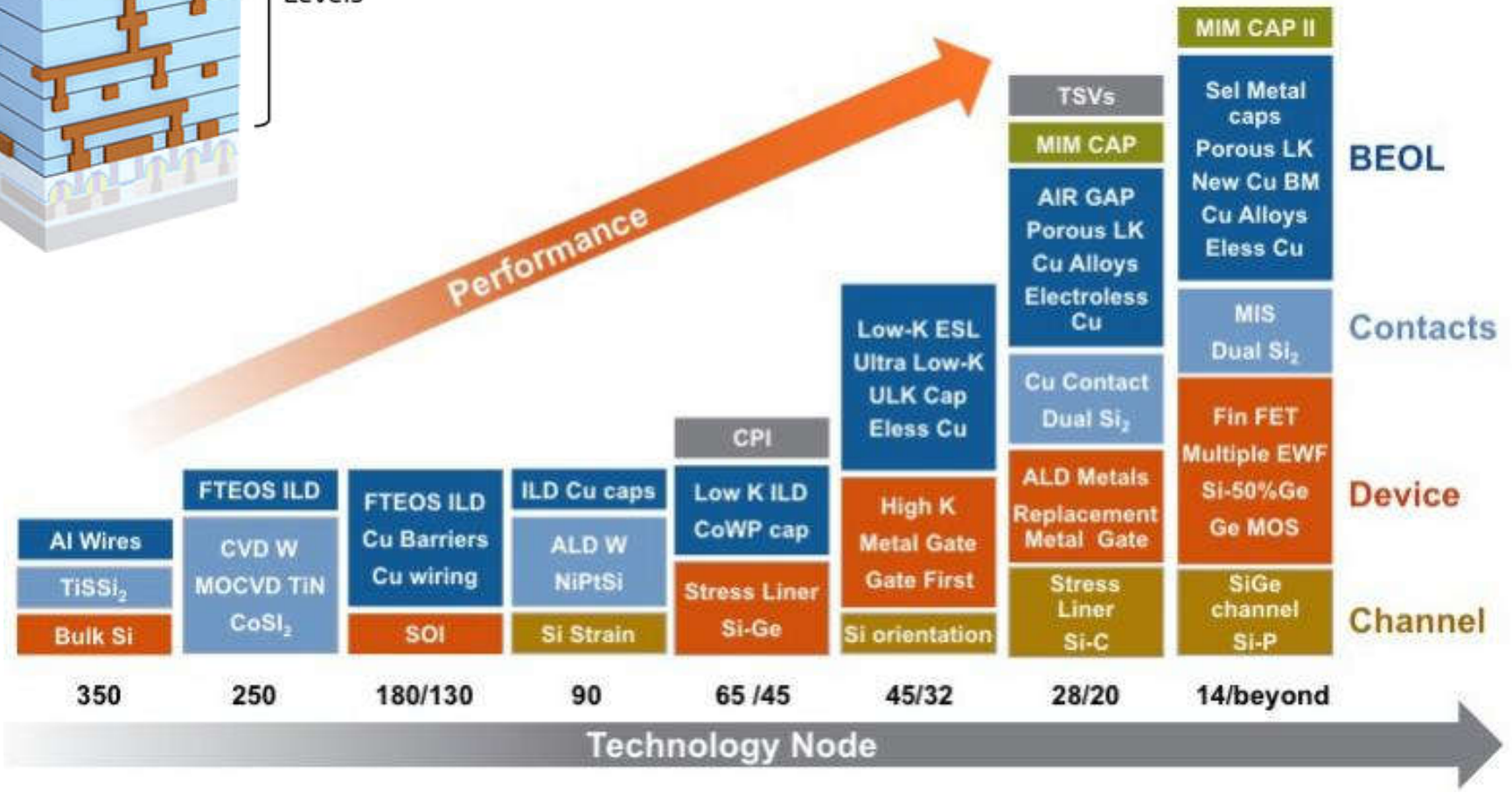
- Copper - electroplating
- Silver - electroless plating
- Liquid Phase Epitaxy (LPE)
- Spin-on glass
- Organics / Quantum Dots

Interconnects for CMOS



copper replaces aluminum below 130 nm

Q: why?



Interconnects for CMOS

Aluminum

- conductive
- reliable and stable
- easy deposition
- easy etching
- low diffusivity in Si and SiO_2
- good adhesion with Si and SiO_2
- low cost
- ...

Interconnects for CMOS

Aluminum

- conductive
- reliable and stable
- easy deposition
- easy etching
- low diffusivity in Si and SiO_2
- good adhesion with Si and SiO_2
- low cost
- ...

vs.

Copper

- more conductive

Copper wins!

Interconnects for CMOS

Reduces RC circuit delay, reduce power consumption

$$t \sim RC$$

$$P \sim I^2 R$$

Materials	Conductivity (10^6 S/m)
Graphene (C)	100
Silver (Ag)	63
Copper (Cu)	60
Gold (Au)	43
Aluminum (Al)	38

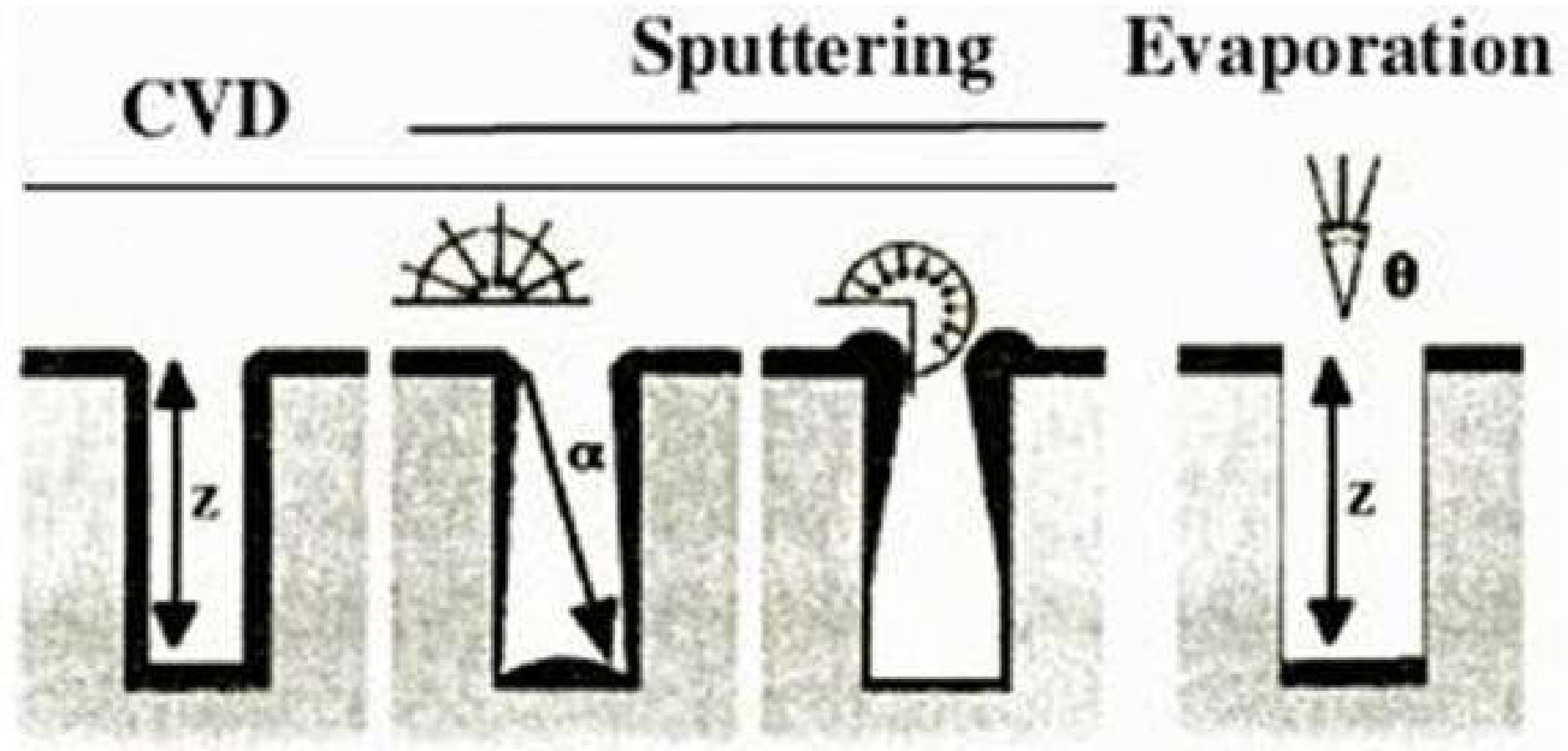
below 130 nm → Copper (Cu)

above 130 nm → Aluminum (Al)

- Al is cheap and easy to deposit
- Ag and Au are expensive
- Cu is cheap and conductive
- Carbon (graphene) is the best

what is next, Ag or Carbon?

Step Coverage



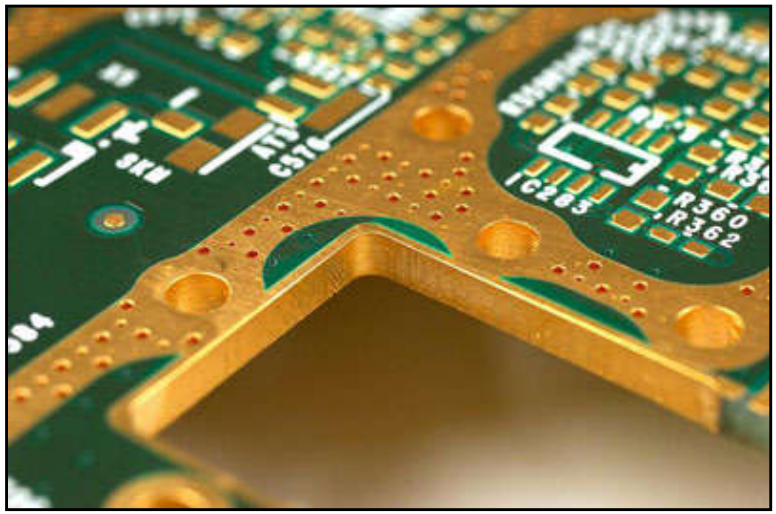
CVD is preferred for via filling

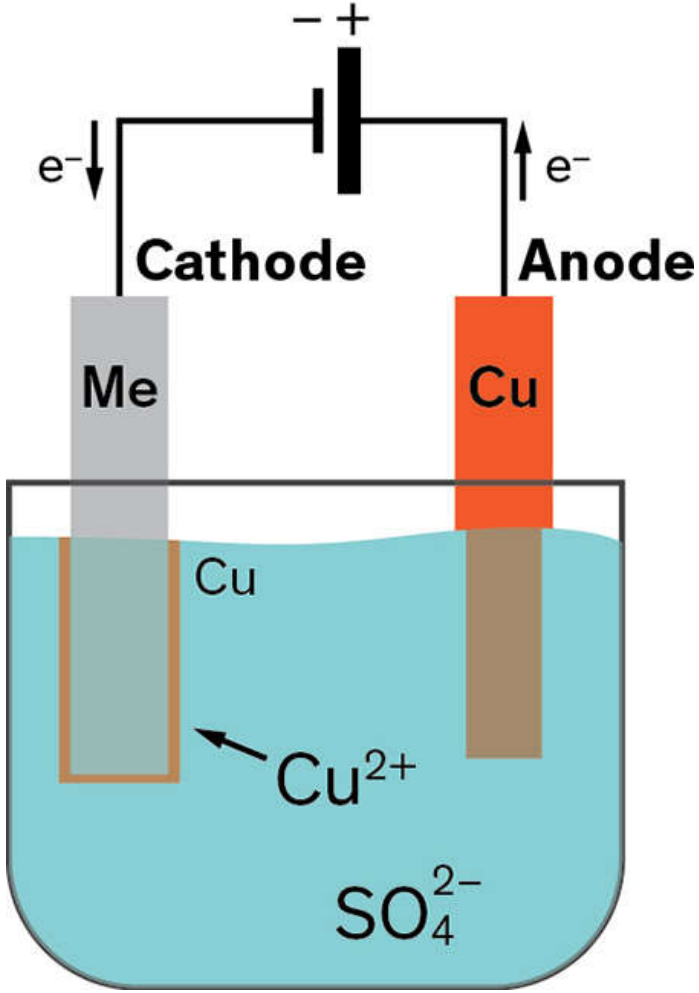
Al, W can be deposited by CVD

but CVD Cu is very difficult ...

Copper Electroplating (电镀)

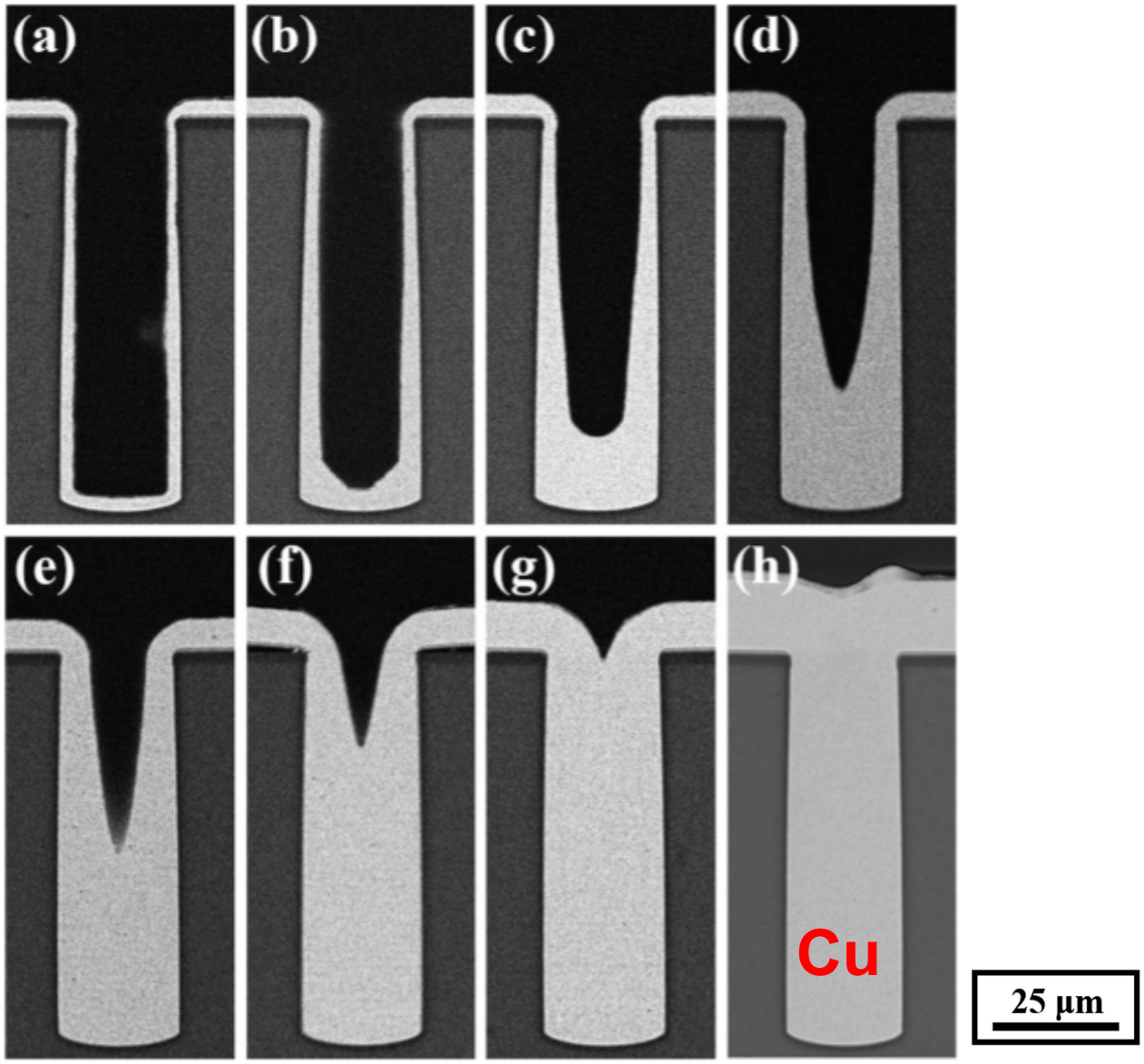
Printed Circuit Board





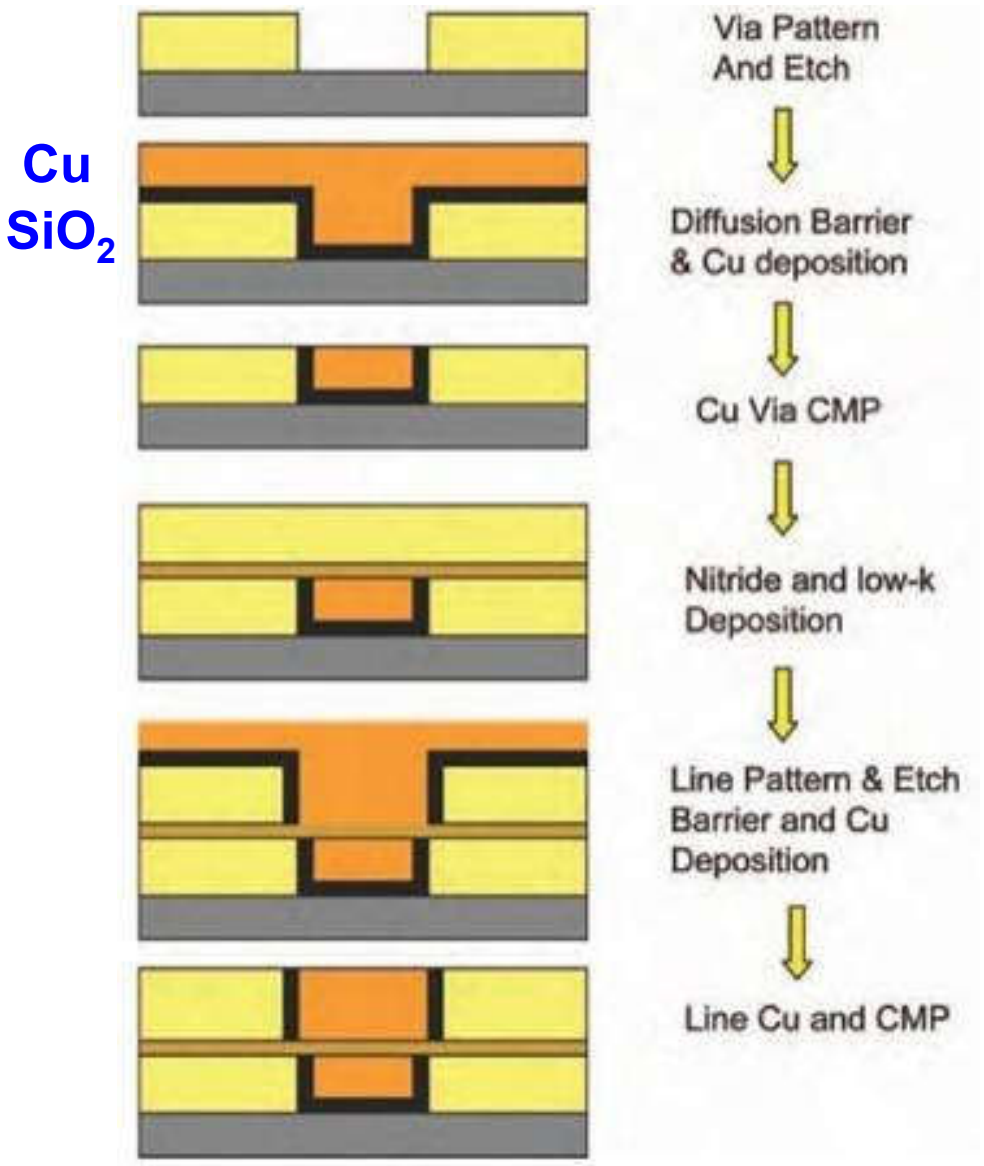
Video

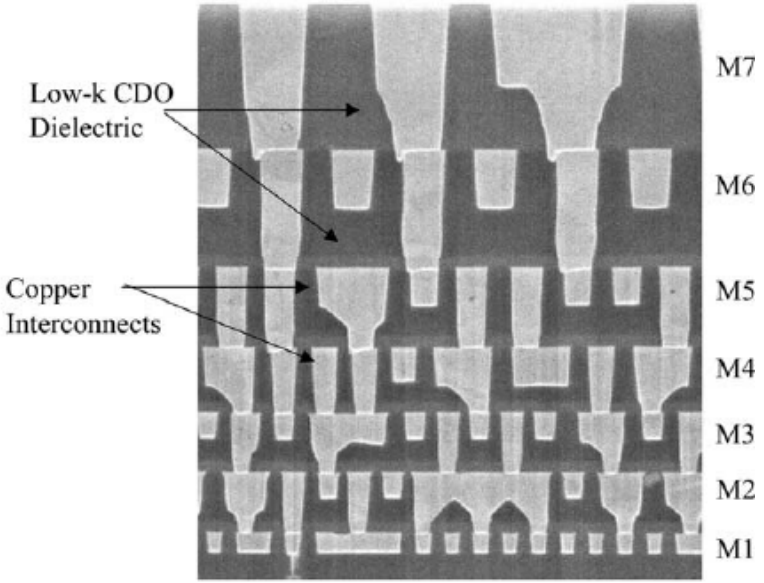
Copper Electroplating (电镀)



F. Wang, *et al.*, *Sci. Rep.* **7,** 46639 (2017)

Damascene Process for Cu





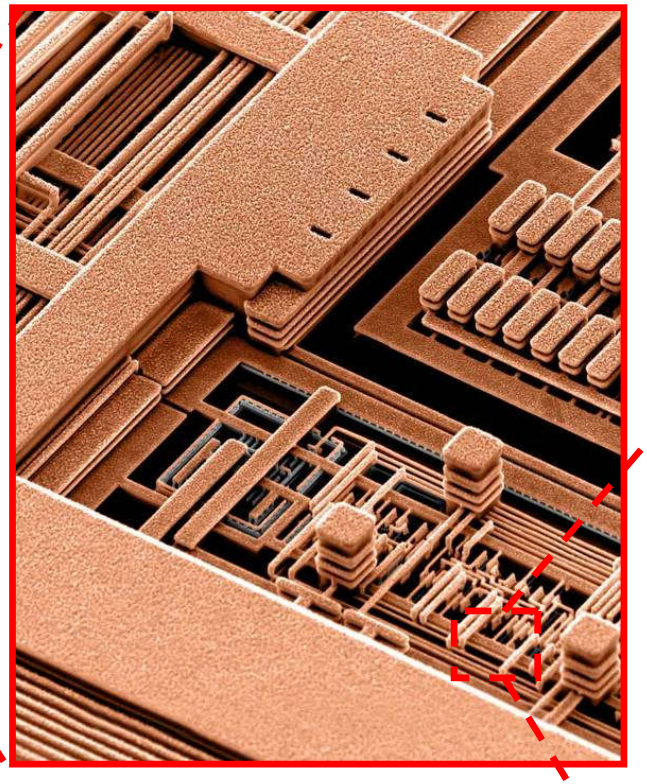
ancient art work

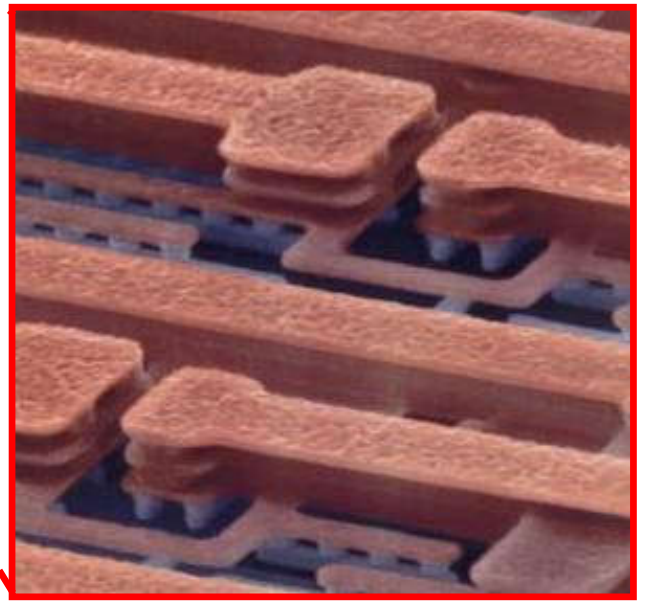
P. C. Andricacos, *et al.*, *IBM J. Res. Develop.* **42,** 567 (1998)

Damascene Process for Cu

Electroplating + CMP

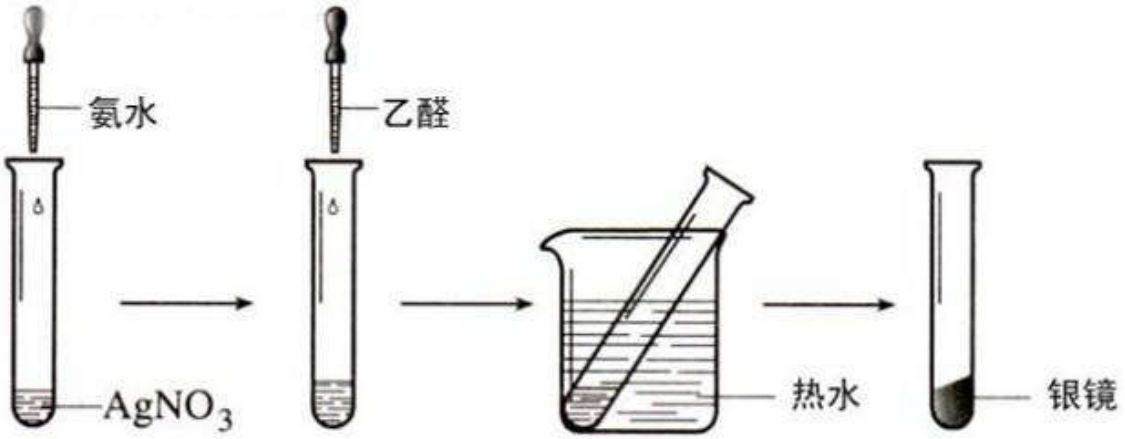
dirtiest process for the most advanced IC



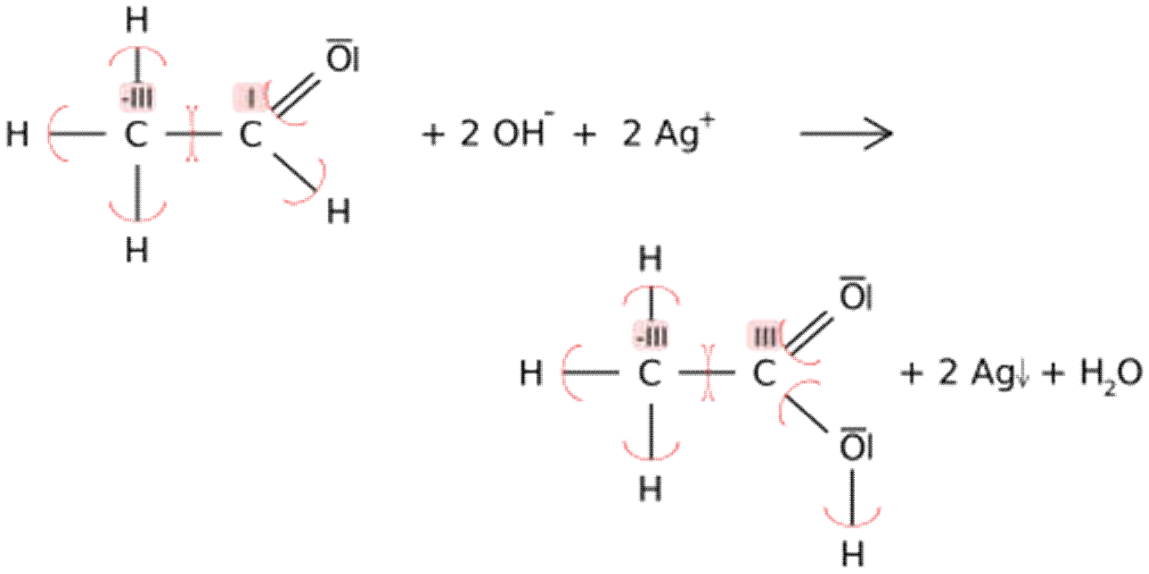


Electroless Plating

silver mirror reaction

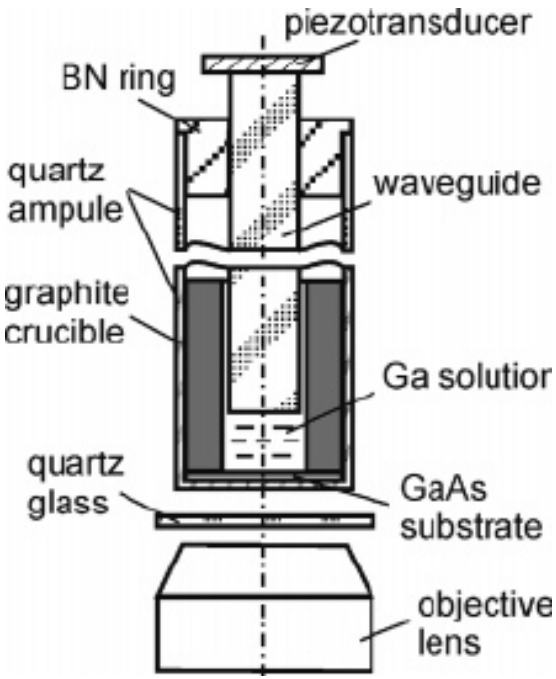


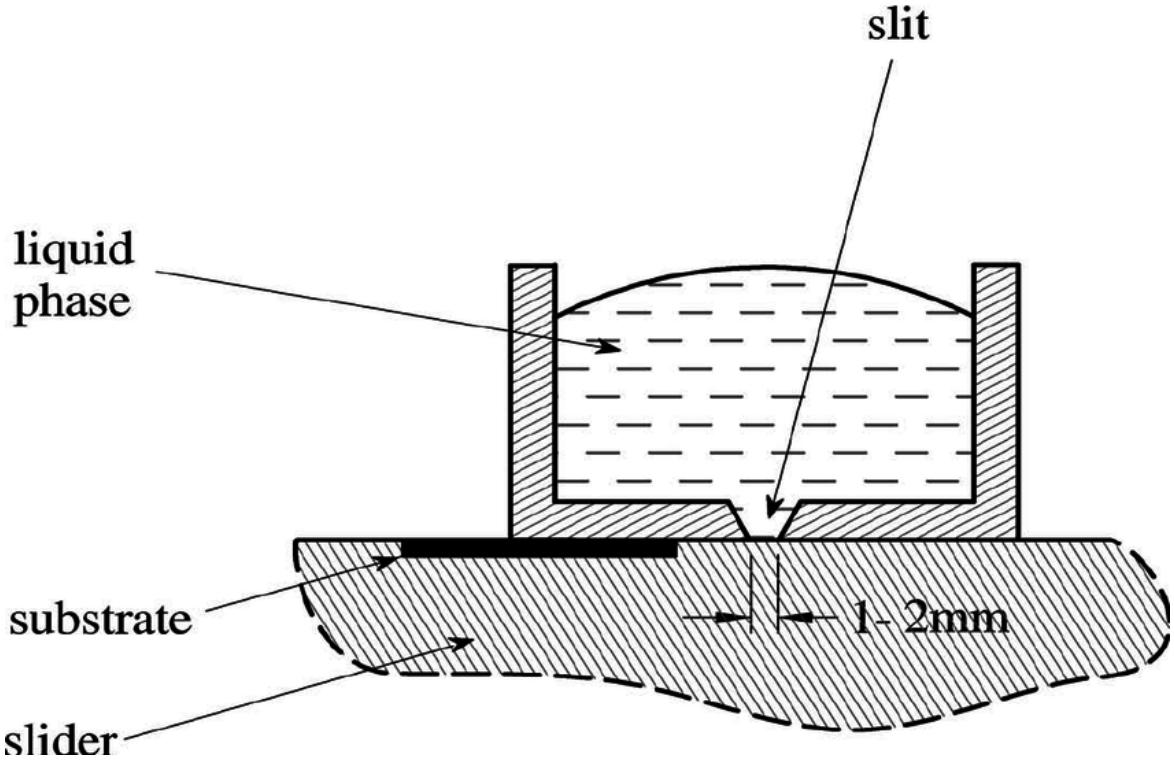
乙醛的银镜反应



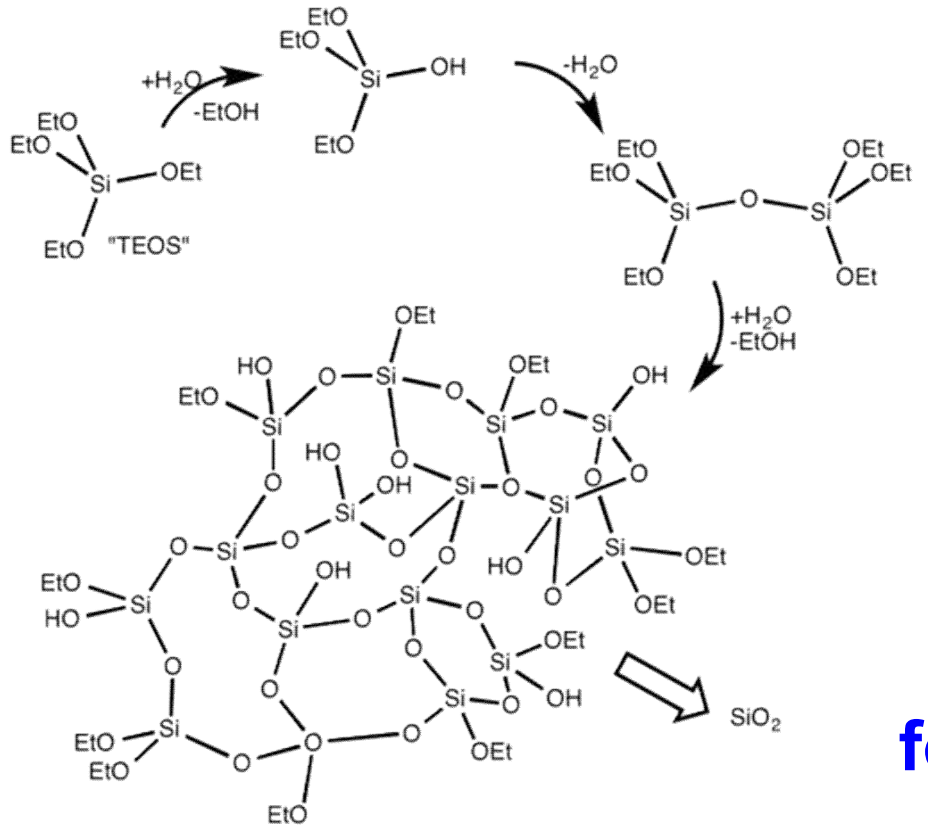
LPE - Liquid Phase Epitaxy

- **Liquid Phase Epitaxy (LPE)**
  - $2Ga\ (l) + 2AsCl_3\ (l) = 2GaAs\ (s) + 3Cl_2\ (g)$

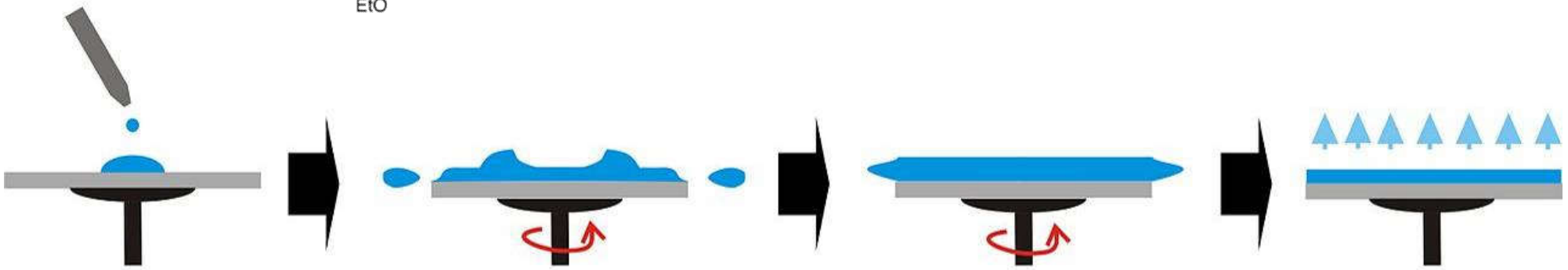




Spin-on Glass (SOG)



form SiO_2 from solvent



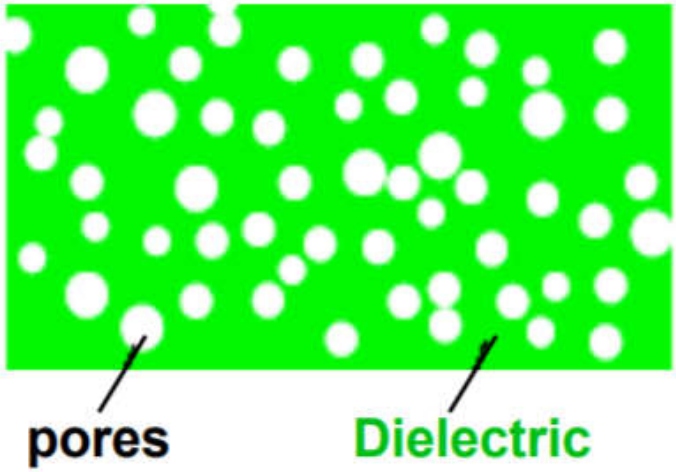
Porous SiO_2 for Low κ Dielectric

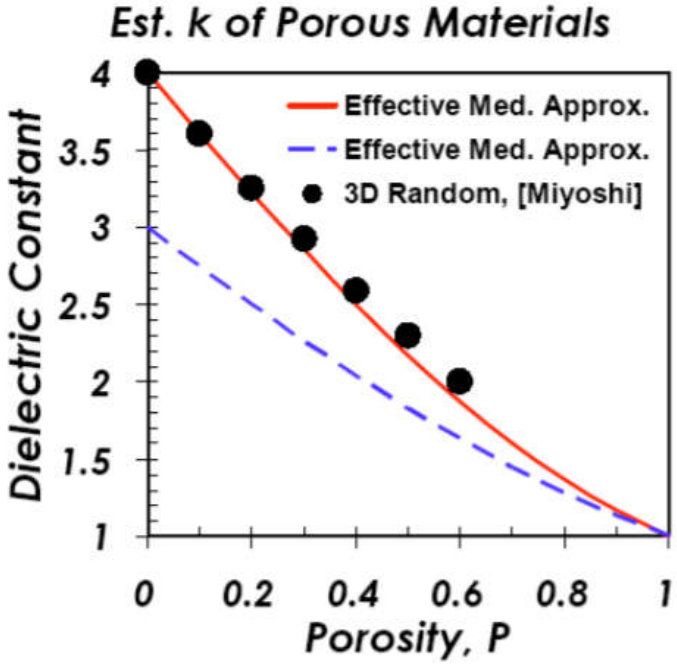
SiO_2

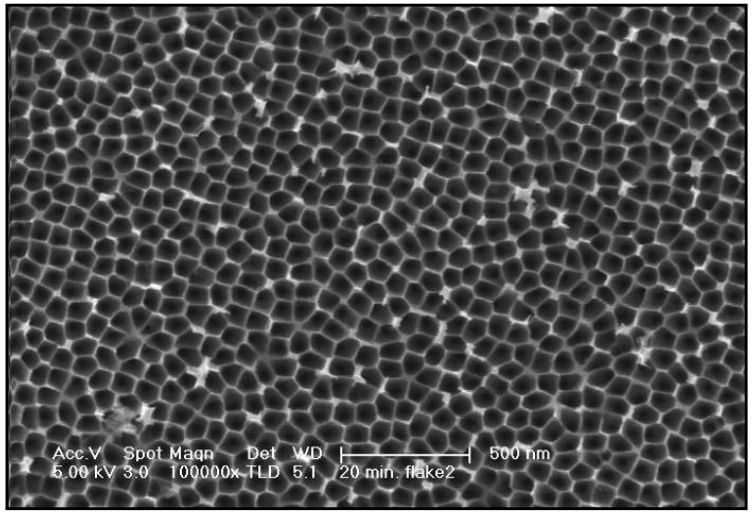
$\kappa = 3.9$

air

$\kappa = 1.0$







prepared by spin-on methods

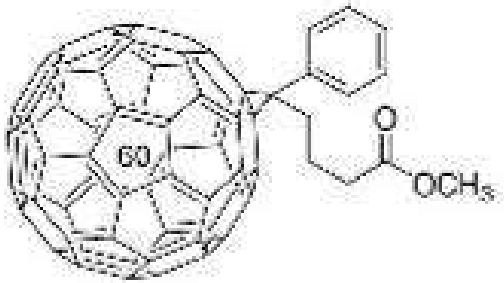
Organic Solar Cells

Solar Cell

Ag (70 nm)
MoO_3 (30 nm)
Dye (30 nm)
PCBM (45 nm)
ZnO (30 nm)
ITO/Glass

9 mm^2

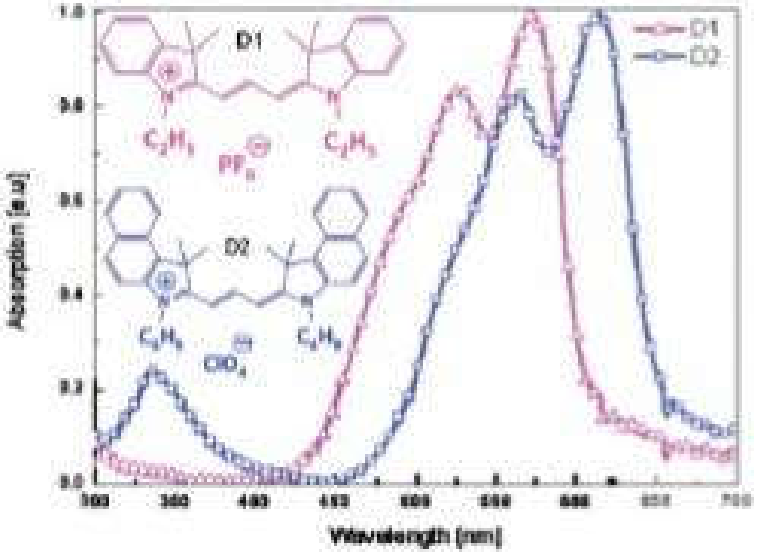
PCMB

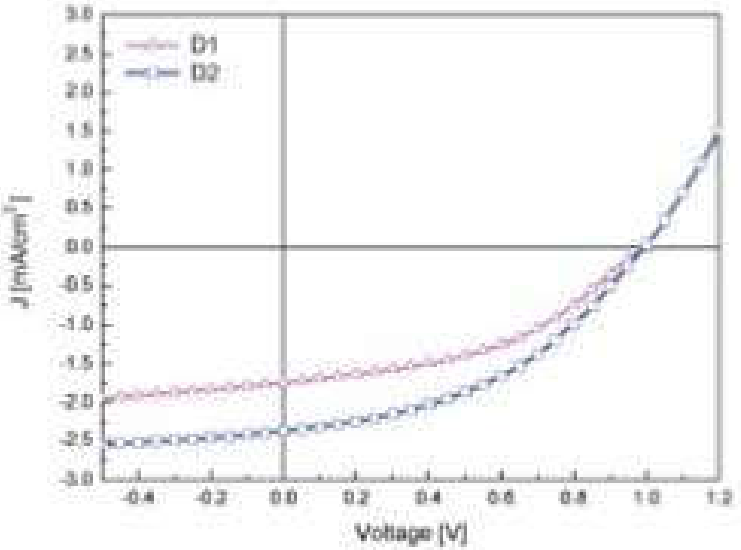


Doctor Blade

Spin coating

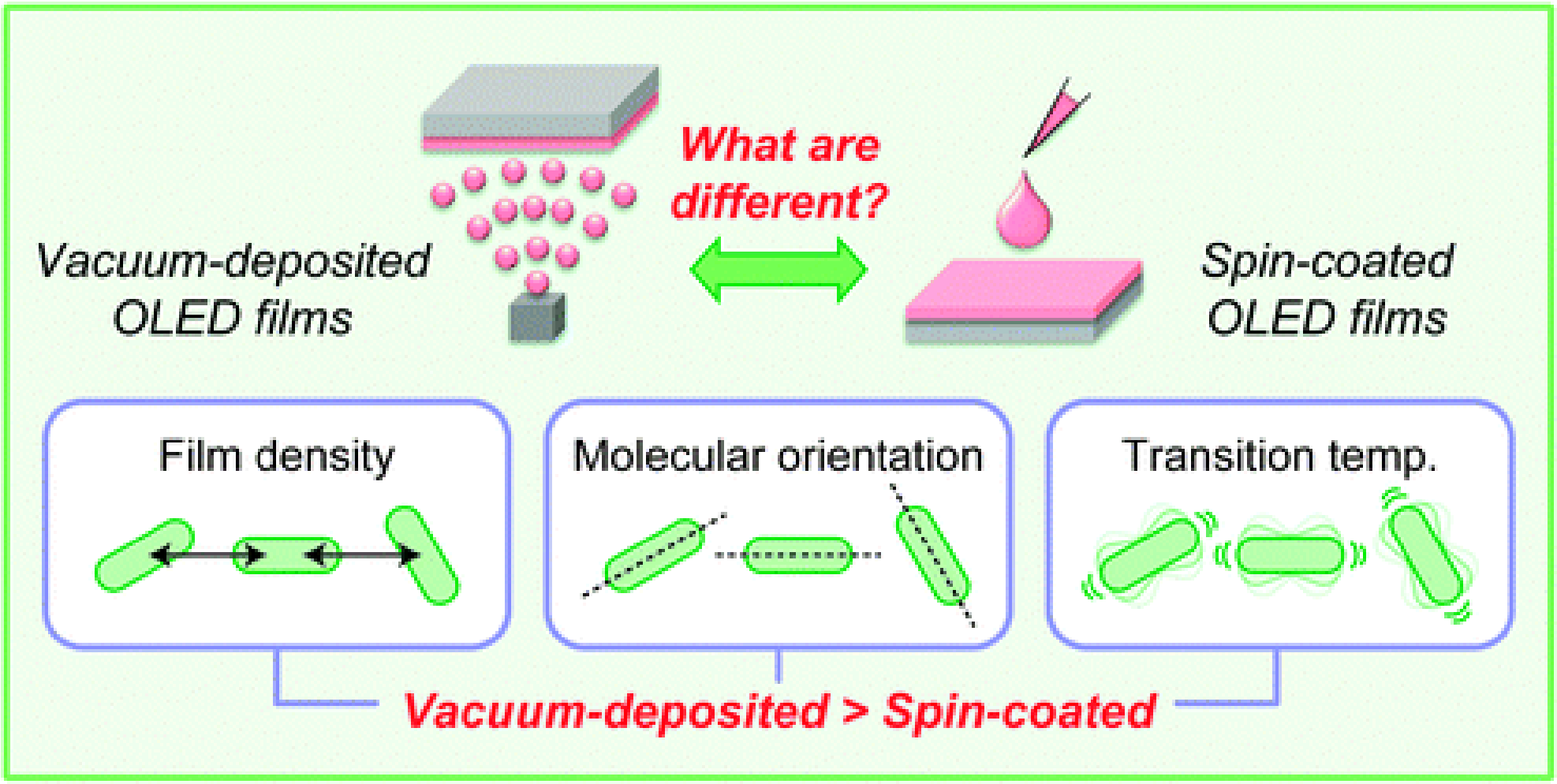
CSD: Spin coating ZnAc/ZnCOOH 400°C





Malinkiewicz et al. RSC Adv. 2 (2012) 3335 (UVEG)

OLEDs

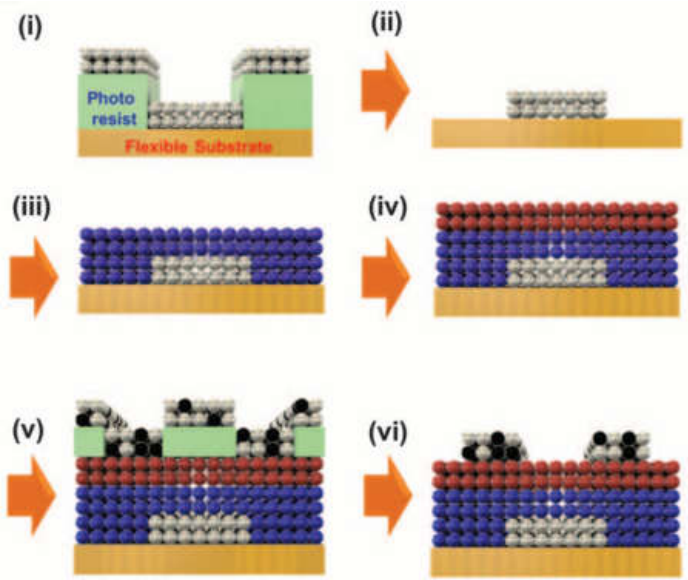

Vacuum-deposited
OLED films
What are
different?
Spin-coated
OLED films
Film density
Molecular orientation
Transition temp.
Vacuum-deposited > Spin-coated

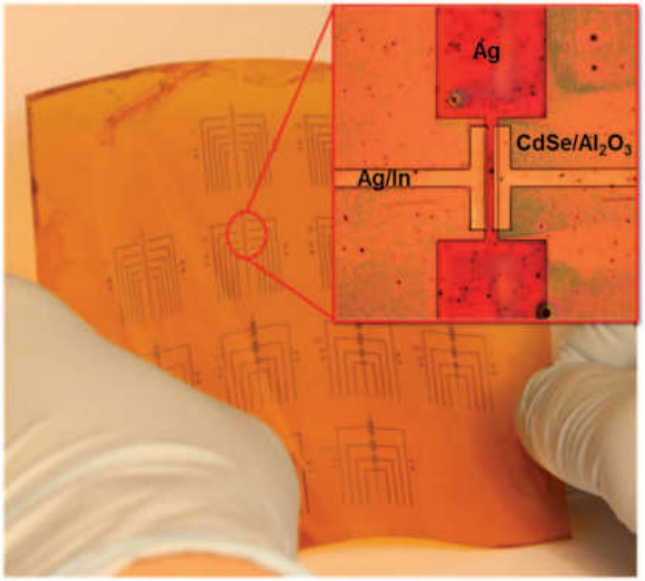
Fully Solution Processed Devices

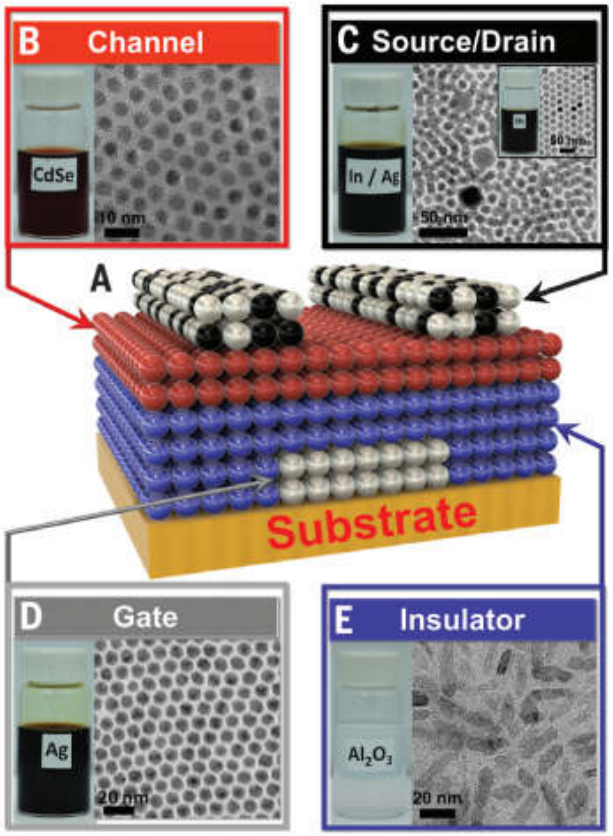
ELECTRONICS

Exploiting the colloidal nanocrystal library to construct electronic devices

Ji-Hyuk Choi,[1,2,3] Han Wang,[4] Soong Ju Oh,[1,5] Taejong Paik,[1] Pil Sung Jo,[1,2] Jinwoo Sung,[6] Xingchen Ye,[7] Tianshuo Zhao,[1] Benjamin T. Diroll,[7] Christopher B. Murray,[1,7] Cherie R. Kagan[1,4,7]*





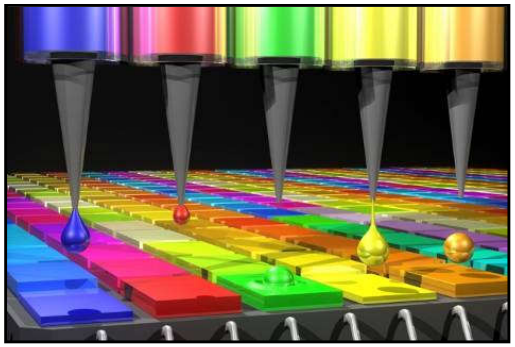


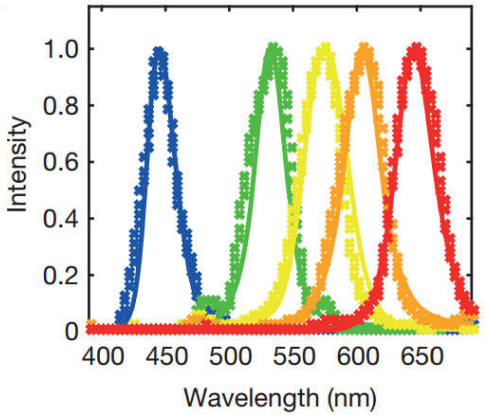
J. Choi, *et al.*, *Science* **352,** 205 (2016)

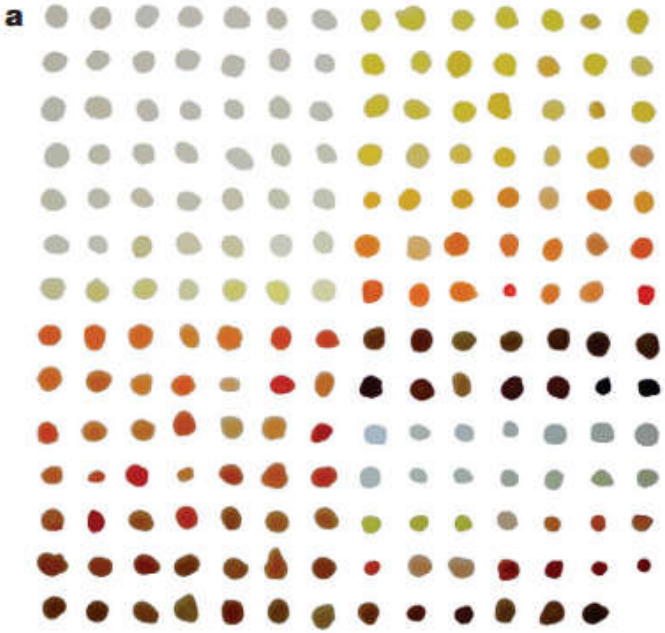
Colloidal Quantum Dots

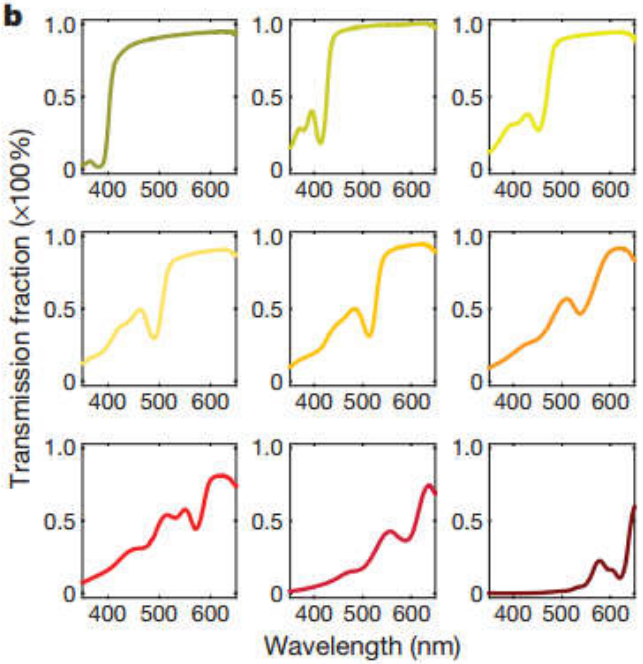
A colloidal quantum dot spectrometer

Jie Bao[1,2,3] & Moungi G. Bawendi[2]



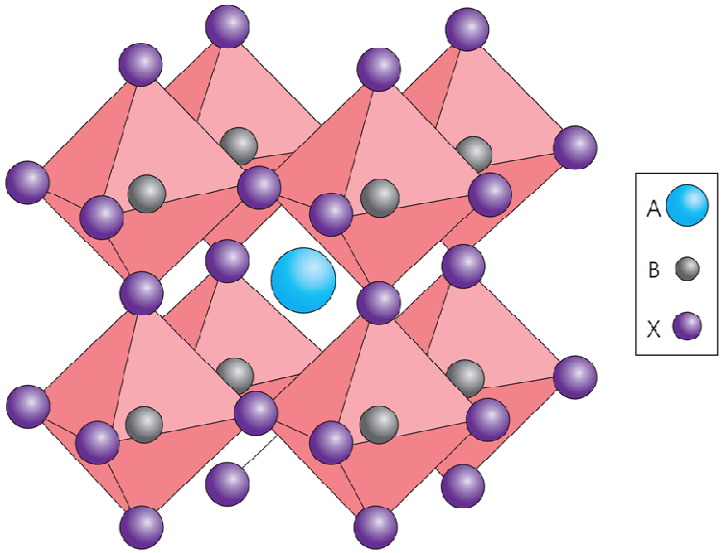


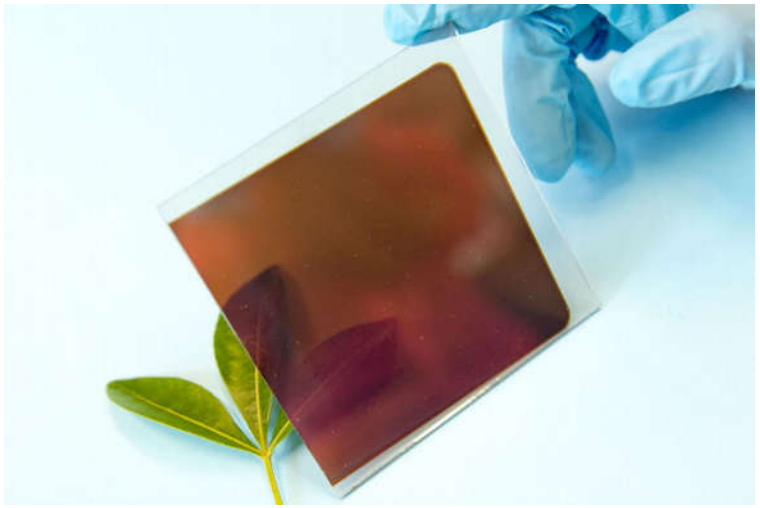




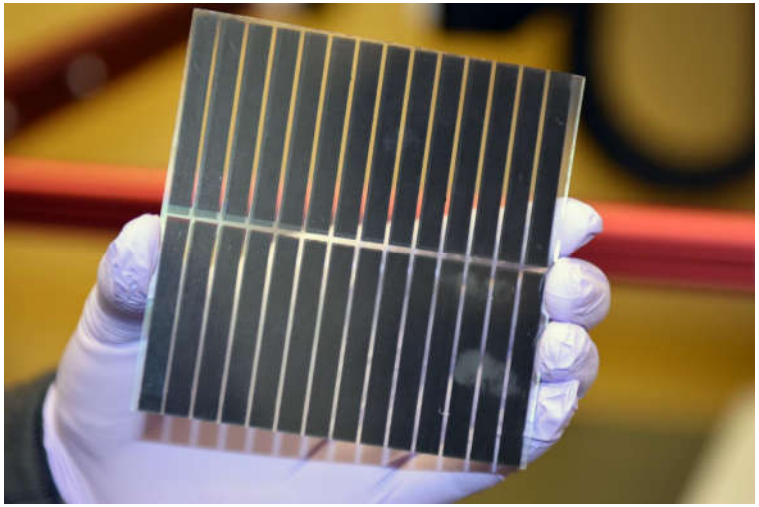
J. Bao and M. G. Bawendi, *Nature* **523,** 67 (2015)

Perovskites (钙钛矿)

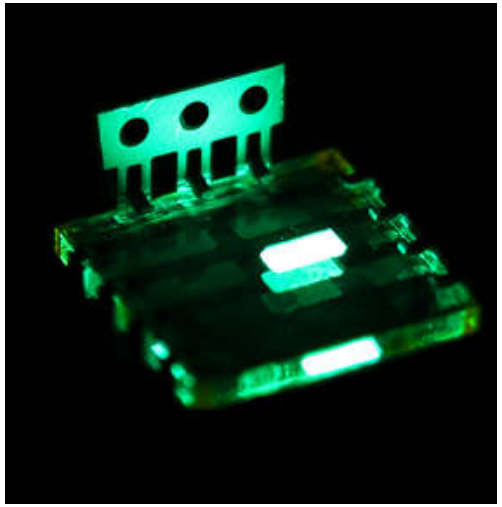




deposit by spin coating or evaporation



solar cells



LEDs

> 20 Nature/Science papers every year