Atomic Layer Deposition

An Introduction to Theory and Applications

Eric Deguns Ph.D.

October 4, 2011

CambridgeNanoTech
Simply ALD

Agenda

- Atomic Layer Deposition Overview
- History
- Applications
- Summary
- Cambridge NanoTech

Methods for Depositing Thin Films

Method	ALD	MBE	CVD	Sputter	Evapor	PLD
Thickness Uniformity	good	fair	good	good	fair	fair
Film Density	good	good	good	good	fair	good
Step Coverage	good	poor	varies	poor	poor	poor
Interface Quality	good	good	varies	poor	good	varies
Low Temp. Deposition	good	good	varies	good	good	good
Deposition Rate	fair	fair	good	good	good	good
Industrial Applicability	varies	varies	good	good	good	poor

The ALD Cycle

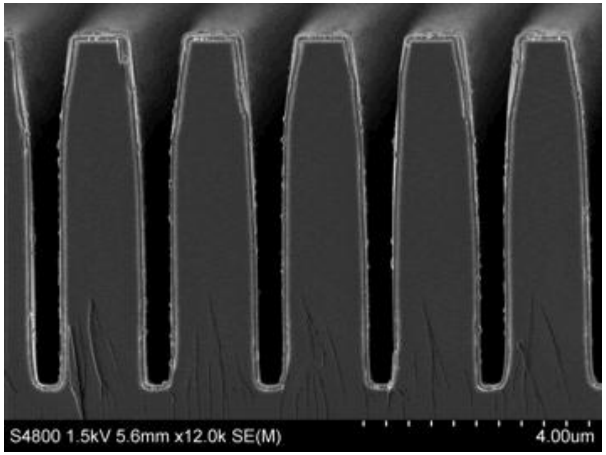
- ALD is a thin film deposition technique where precursors are sequentially introduced to the surface, where they ***react directly with the surface***, to form *sub-monolayers* of film

- A single ALD cycle consists of the following steps:
  - 1) Exposure of the first precursor
  - 2) Purge or evacuation to remove by-products
  - 3) Exposure of the second precursor
  - 4) Purge or evacuation of the reaction chamber

ALD Deposits Thin Inorganic Films

Benefits of ALD

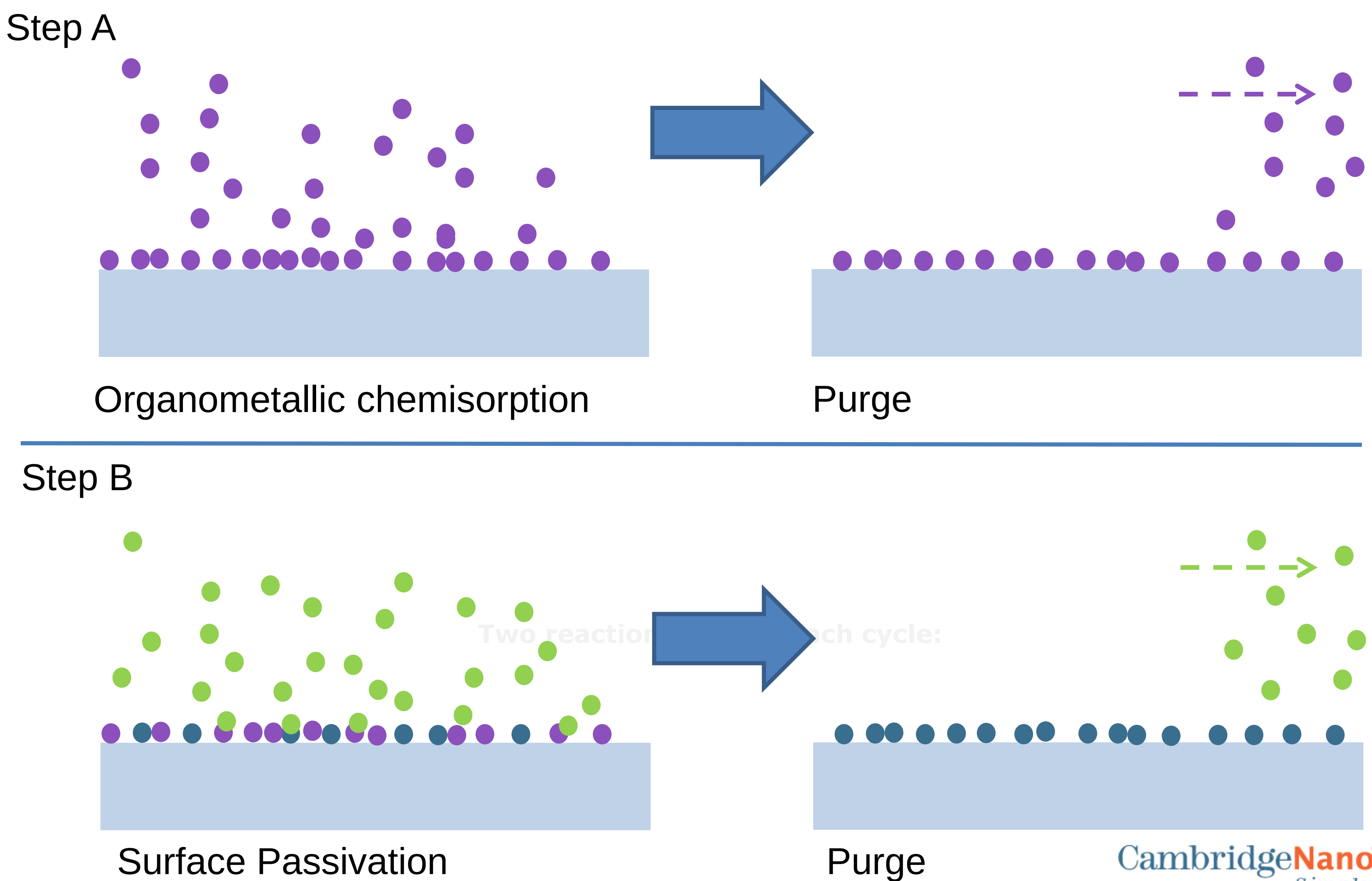
100 nm Al_2O_3 coating on Si wafer



- **Perfect films**
  - Digital control of film thickness
  - Excellent repeatability
  - High film density
  - Amorphous or crystalline films
  - Ultra thin films: <10nm possible
- **Conformal Coating**
  - Perfect 3D conformality
  - Ultra high aspect ratio (>2,000:1)
  - Large area thickness uniformity
  - Atomically flat and smooth coating
- **Challenging Substrates**
  - Gentle deposition process for sensitive substrates
  - Low temperature and low stress
  - Excellent adhesion
  - Coats challenging substrates – even teflon

Typical ALD Film thickness 10 Å – 2000 Å

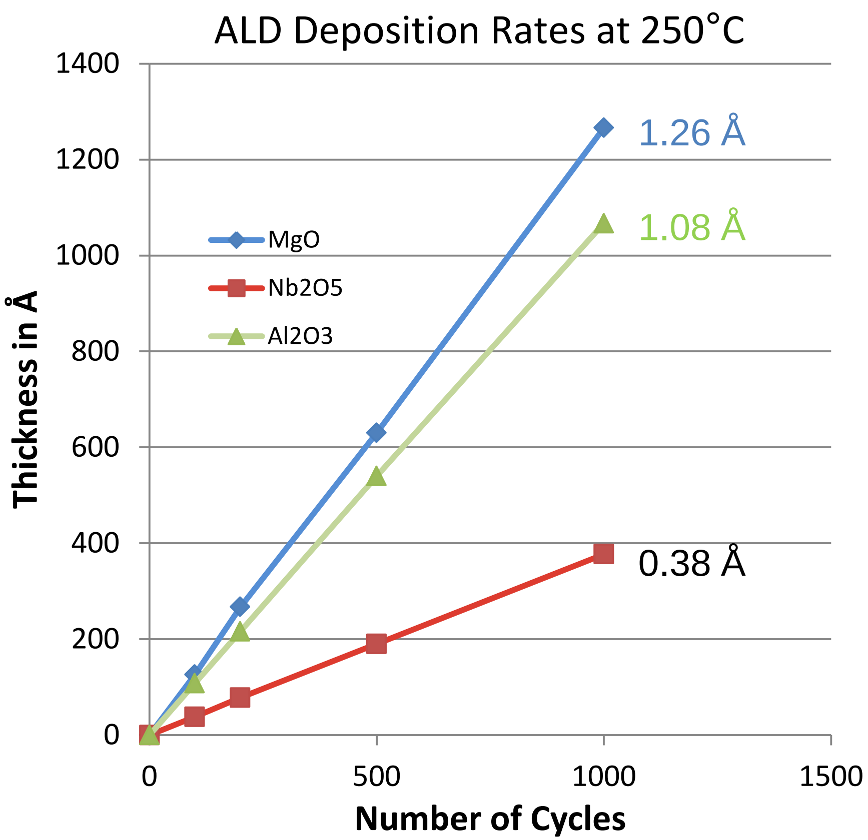
ALD is a Two-Part Reaction



CambridgeNanoTech
Simply ALD

ALD Films

- Films deposited with digital control of thickness; “built layer-by layer”
- Each film has a characteristic growth rate for a particular temperature



Oxides

Al_2O_3, HfO_2, La_2O_3, SiO_2, TiO_2, ZnO, ZrO_2, Ta_2O_5, In_2O_3, SnO_2, ITO, FeO_x, NiO_2, MnO_x, Nb_2O_5, MgO, Er_2O_3, WO_x

Nitrides

WN, Hf_3N_4, Zr_3N_4, AlN, TiN, TaN, NbN_x

Metals

Ru, Pt, W, Ni, Co, Pd, Rh, Cu

Sulphides

ZnS, SnS, Cu_2S

CambridgeNanoTech
Simply ALD

ALD Periodic Table

Periodic Table | ALD Films

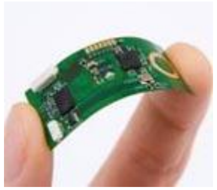
O:Oxide
N:Nitride
M:Metal
P:Phosphide/Asenide
S:Sulphide/Selenide/Telluride
C:Carbide
F:Flouride
D:Dopant

O Oxide of this element has been deposited by the ALD community
O Recipe for this material is available from CNT staff or customer base

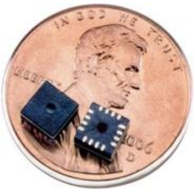
H 1																	He 2
O Li 3	Be 4											O N B 5 D	C 6	N 7	O 8	F 9	Ne 10
Na 11	**O** Mg 12 F											**O** **N** M P Al 13 **D**	**O** N M Si 14 C	P 15	S 16	Cl 17	Ar 18
K 19	O Ca 20 S F	O Sc 21	**O** **N** M Ti 22 S	O V 23	O Cr 24	**O** N M Mn 25 S D	**O** N **M** Fe 26	**O** N **M** Co 27	**O** N **M** Ni 28	O N M Cu 29 S D	**O** Zn 30 **S** F **D**	**O** **N** P Ga 31 D	O M Ge 32	As 33	Se 34	Br 35	Kr 36
Rb 37	O Sr 38 S F	O Y 39	**O** **N** Zr 40	**O** **N** Nb 41	O N M Mo 42	Tc 43	O **M** Ru 44	O M Rh 45	O **M** Pd 46	O M Ag 47	Cd 48 S	**O** N P In 49 S	**O** Sn 50 S D	O M Sb 51 D	Te 52	I 53	Xe 54
Cs 55	O Ba 56 S	**O** La 57 S F	**O** **N** Hf 72 S F	**O** N M Ta 73 C	**O** **N** **M** W 74	O Re 75	O Os 76	O M Ir 77	O **M** Pt 78	Au 79	Hg 80 S	Tl 81	O Pb 82 S D	O Bi 83	Po 84	At 85	Rn 86
Fr 87	Ra 88	Ac 89	Rf 104	Db 105	Sg 106	Bh 107	Hs 108	Mt 109									
				O Ce 58 D	O Pr 59	Nd 60	Pm 61	O Sm 62	O Eu 63 D	O Gd 64	O Tb 65 D	O Dy 66	O Ho 67	**O** Er 68	O Tm 69 D	O Yb 70	O Lu 71
				Th 90	Pa 92	U 93	Np 94	Pu 95	Am 96	Cm 97	Bk 98	Cf 100	Es 101	Fm 102	Md 104	No 4	Lr 4

Applications for ALD

Optical
Antireflection
Optical filters
OLED layers
Photonic crystals
Transparent conductors
Electroluminescence
Solar cells
Lasers
Integrated optics
UV blocking
Colored coatings



Semi / Nanoelectronics
Flexible electronics
Gate dielectrics
Gate electrodes
Metal Interconnects
Diffusion barriers
DRAM
Multilayer-capacitors
Read heads

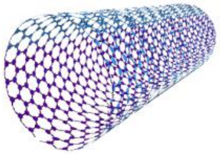


MEMS
Etch resistance
Hydrophobic / antistiction

Chemical
Catalysis
Fuel cells

Other applications
Internal tube liners
Nano-glue
Biocompatibility
Magnetic materials

Wear resistant
Blade edges
Molds and dies
Solid lubricants
Anti corrosion



Nanostructures
Inside pores
Nanotubes
Around particles
AFM tips
Graphene functionalization

CambridgeNanoTech
Simply ALD

ALD History

1950-1962: "Molecular Layering" Prof. S.I. Kol'tsov and Prof. V.B. Aleskovskii, Russia

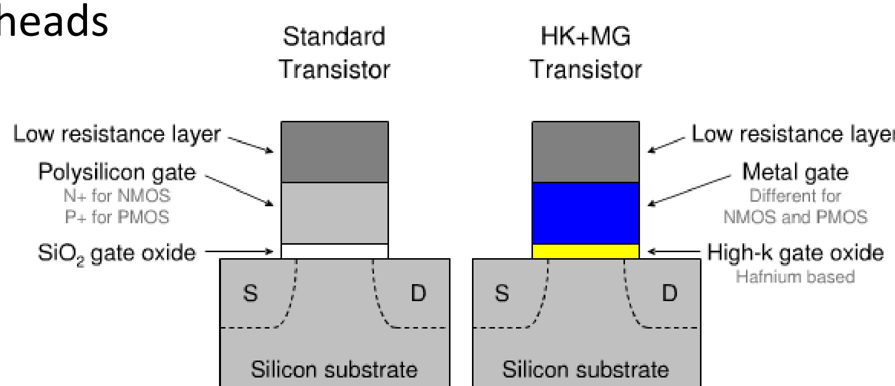
1972: "Atomic Layer Epitaxy" : Dr. T. Suntola, Finland

Mid 1970-1980s: Thin Film Electroluminescent Displays
Mass produced using "ALE" ZnS

1980s-1990s: "Dark Ages of ALD"

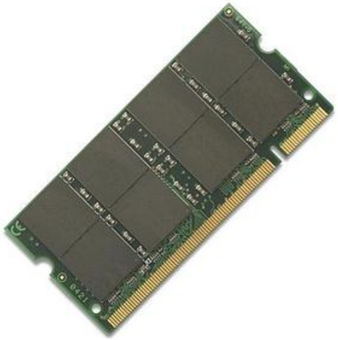
Mid 1990s: research interest in ALD renewed – Microlectronics

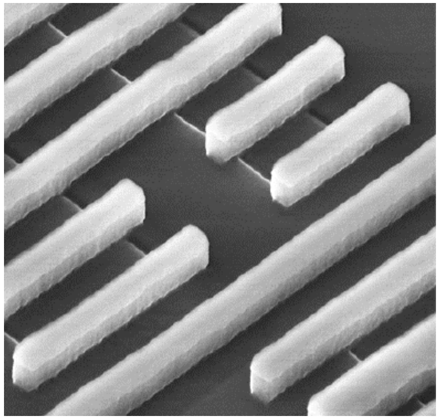
Early 2000s: HDD Write heads
2007: Intel 45nm High-K



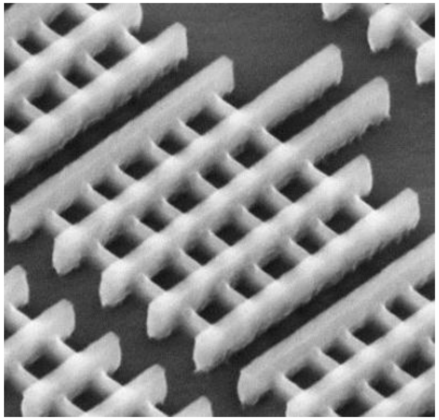
CambridgeNanoTech
Simply ALD

ALD For Microelectronics





32nm Planar Transistor

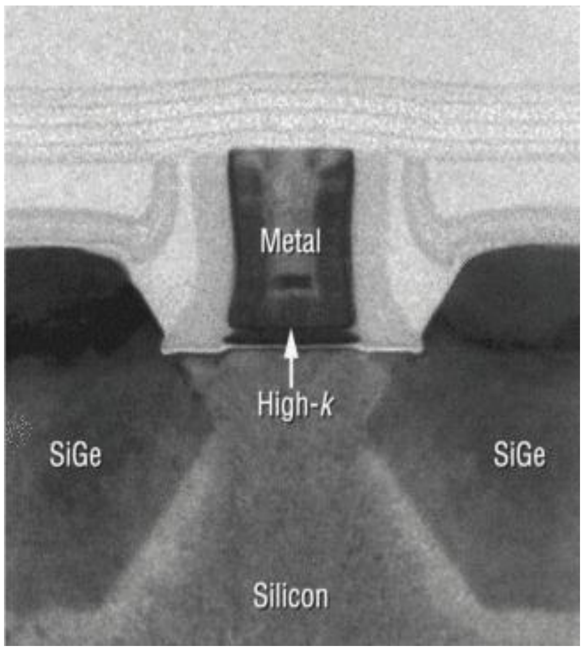


22nm 3-D Transistor

CambridgeNanoTech
Simply ALD

ALD For Microelectronics

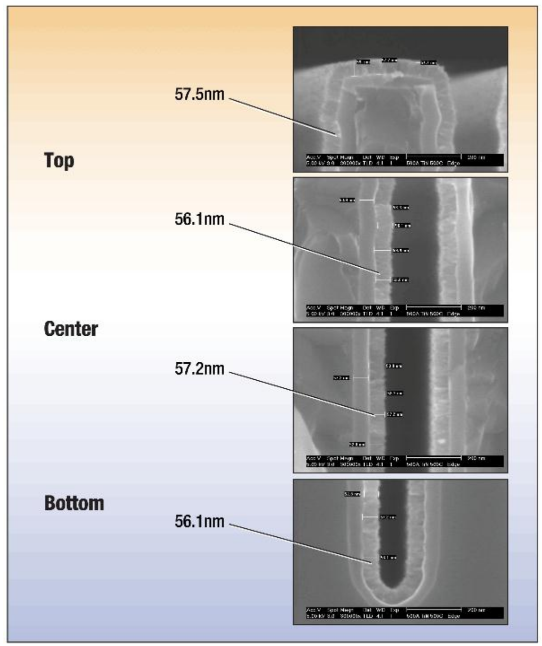
High-K



HfO$_2$, ZrO$_2$, Al$_2$O$_3$, SiO$_2$, HfSiO, ZrSiO…

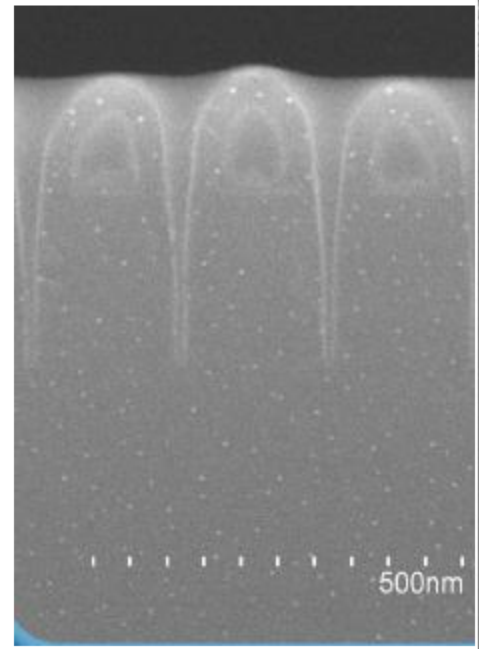
Diffusion Barrier

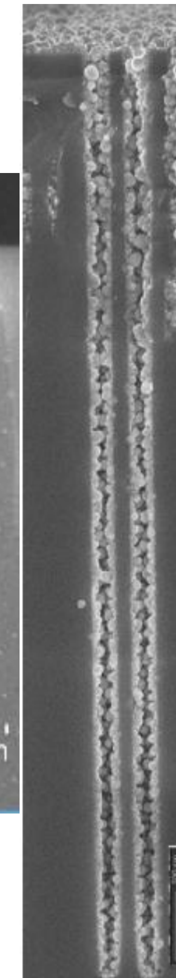
Step coverage of batch ALD TiN film in 32:1 trenches



TiN, TaN, TaCN, WN, WC$_x$N$_y$, Ru, TiSiN…

Glue/Seed Layer



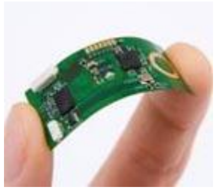


Ru, Cu, Mn, Pd

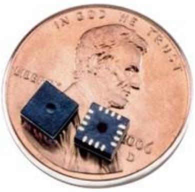
CambridgeNanoTech
Simply ALD

Applications for ALD

Optical
Antireflection
Optical filters
OLED layers
Photonic crystals
Transparent conductors
Electroluminescence
Solar cells
Lasers
Integrated optics
UV blocking
Colored coatings



Semi / Nanoelectronics
Flexible electronics
Gate dielectrics
Gate electrodes
Metal Interconnects
Diffusion barriers
DRAM
Multilayer-capacitors
Read heads

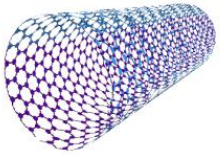


MEMS
Etch resistance
Hydrophobic / antistiction

Chemical
Catalysis
Fuel cells

Other applications
Internal tube liners
Nano-glue
Biocompatibility
Magnetic materials

Wear resistant
Blade edges
Molds and dies
Solid lubricants
Anti corrosion

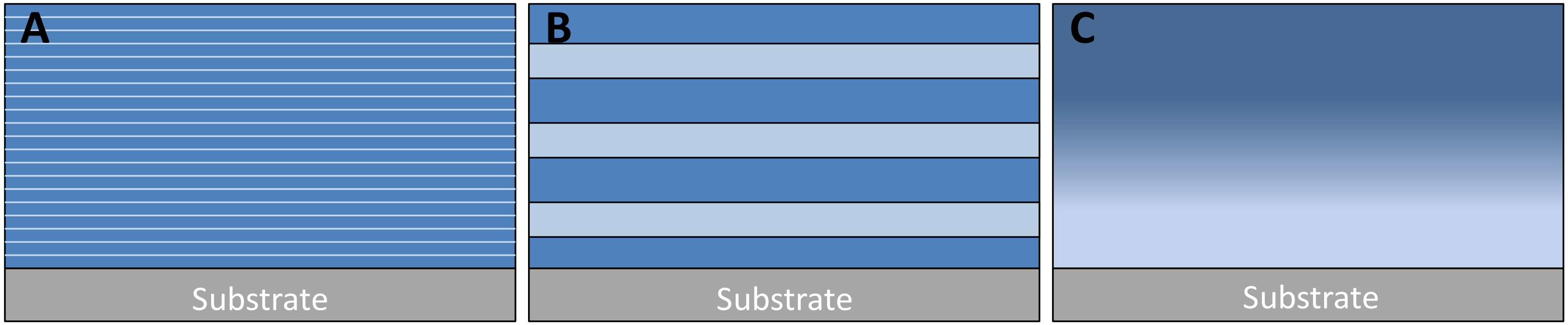


Nanostructures
Inside pores
Nanotubes
Around particles
AFM tips
Graphene functionalization

CambridgeNanoTech
Simply ALD

Variety of Films Possible

- (A) Doped films: single “layers” of dopant film in between bulk
- (B) Nanolaminate Films: stacks of alternating layers
- (C) Graded films: composition slowly changes from material A to material B



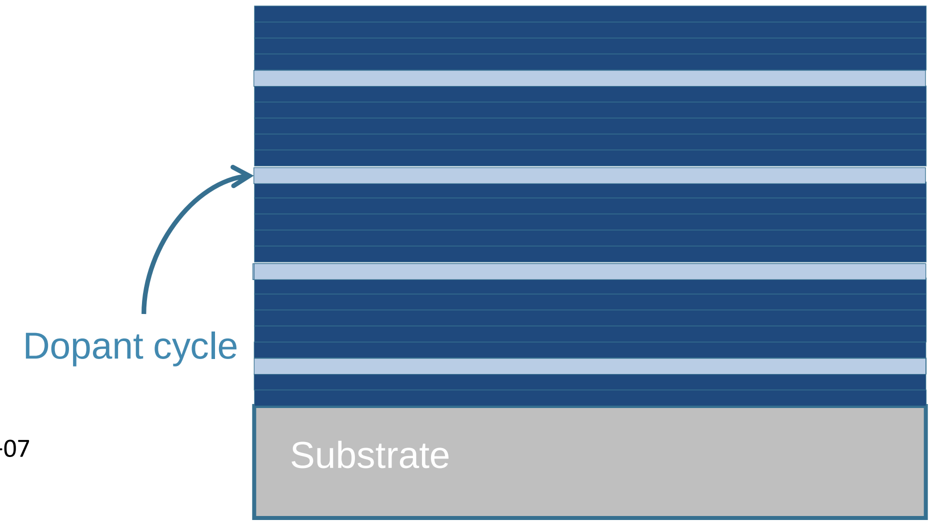
Tunable Film Properties

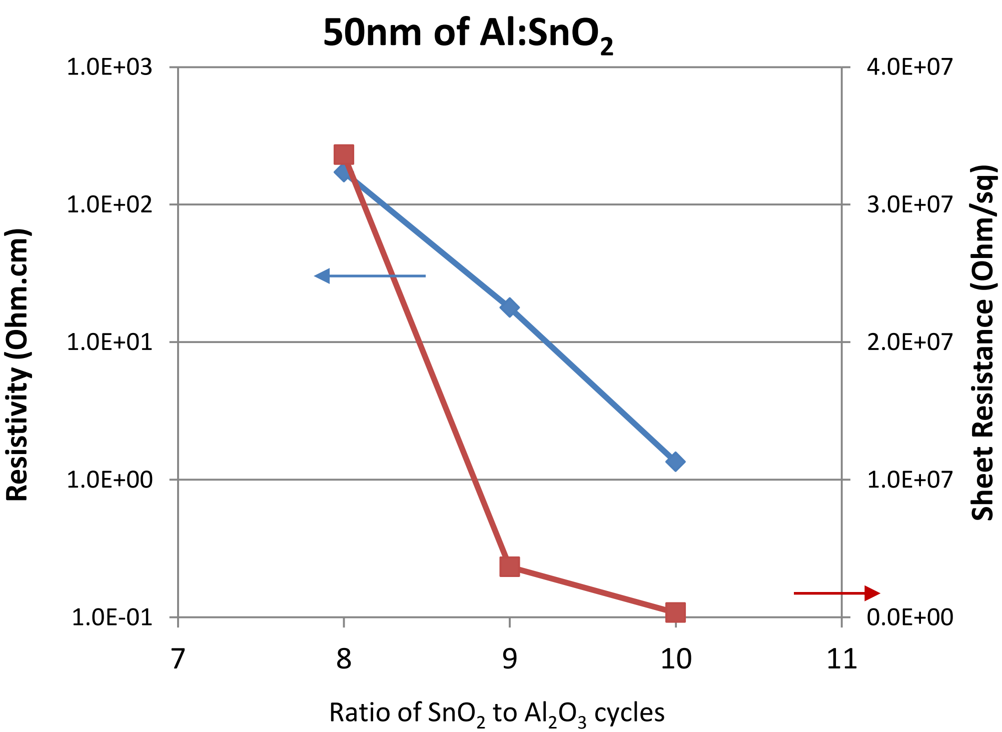
Main Film component:

$Sn(NMe_2)_4 + O_3 \rightarrow SnO_2$

Dopant:

$AlMe_3 + H_2O \rightarrow Al_2O_3$





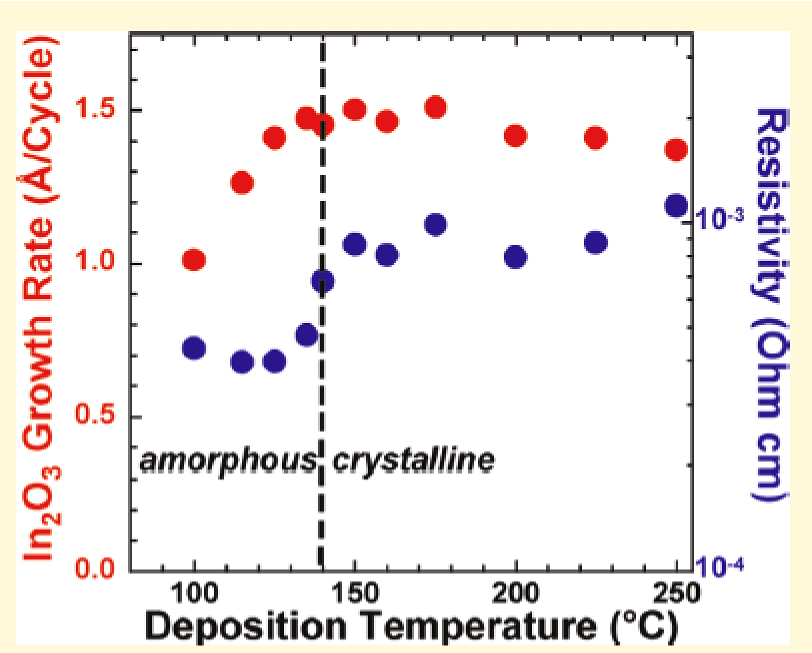
- Electrical resistivity tunable
- Films behave as bulk, doped films
- No post-deposition activation

CambridgeNanoTech
Simply ALD

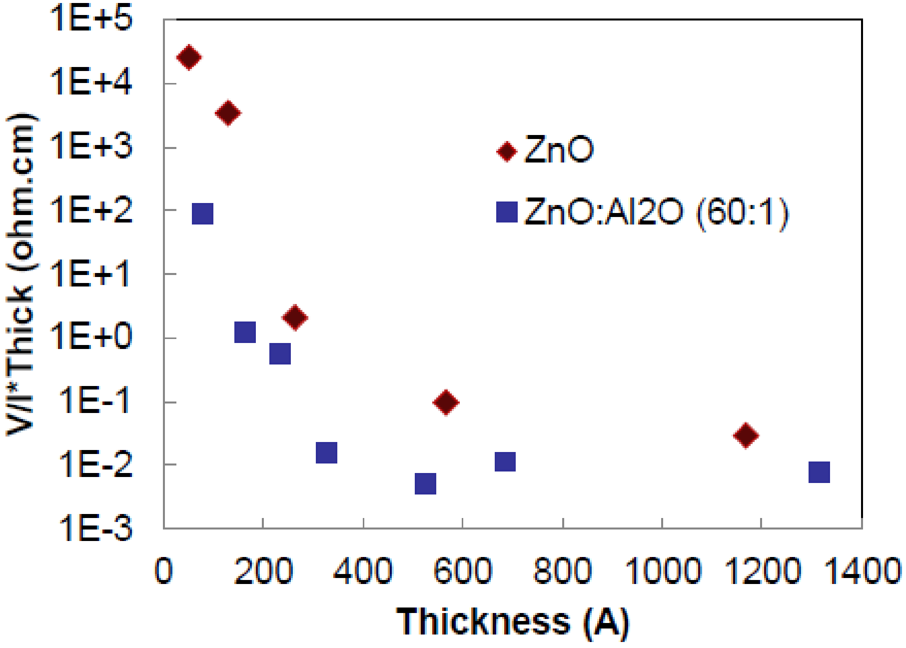
ALD for TCOs

- Current "gold standard" TCOs are F:SnO_2 or ITO; low resistivity, high transparency
- Both ITO and ZnO:D systems can be tuned for optical transparency, substrate effects

In_2O_3 only



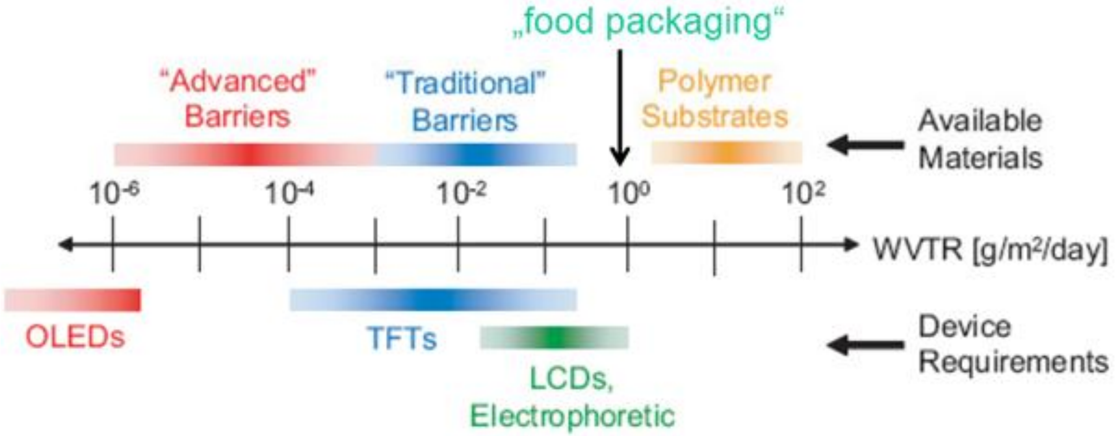
Aluminum-doped ZnO



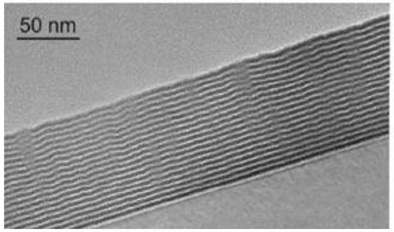
Libera, J.A. Elam, J.W. **2011** *Chem Mater.* ASAP.

CambridgeNanoTech Simply ALD

ALD for Moisture Barriers



- Improved performance water and oxygen barrier by using nanolaminate layers of 5nm Al_2O_3 and ZrO_2
- Water Vapor Transmission Rate (WVTR) $<10^{-6}$ g/m^2 day demonstrated

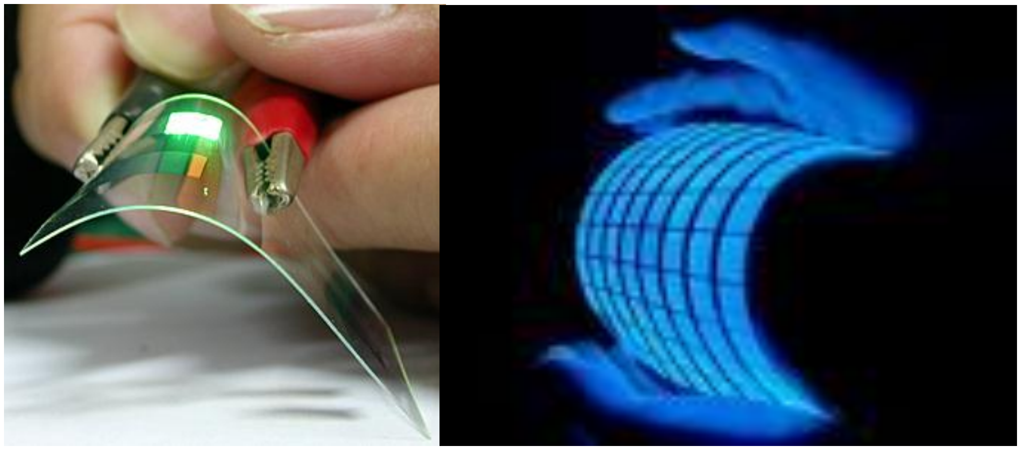


Advanced Materials **2009**, *21*, 1845-1849

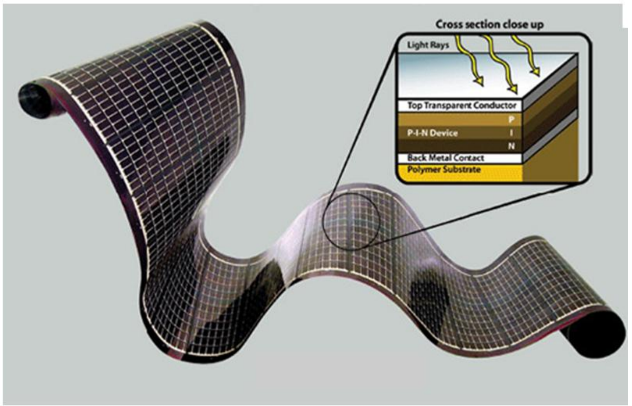
CambridgeNanoTech
Simply ALD

Flexible Electronics

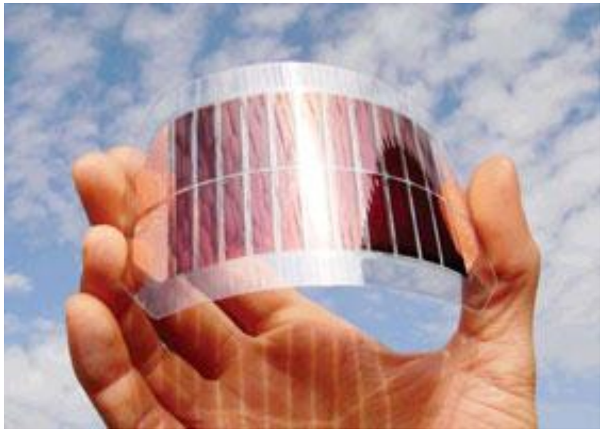
OLEDs



ePaper



Flexible Solar

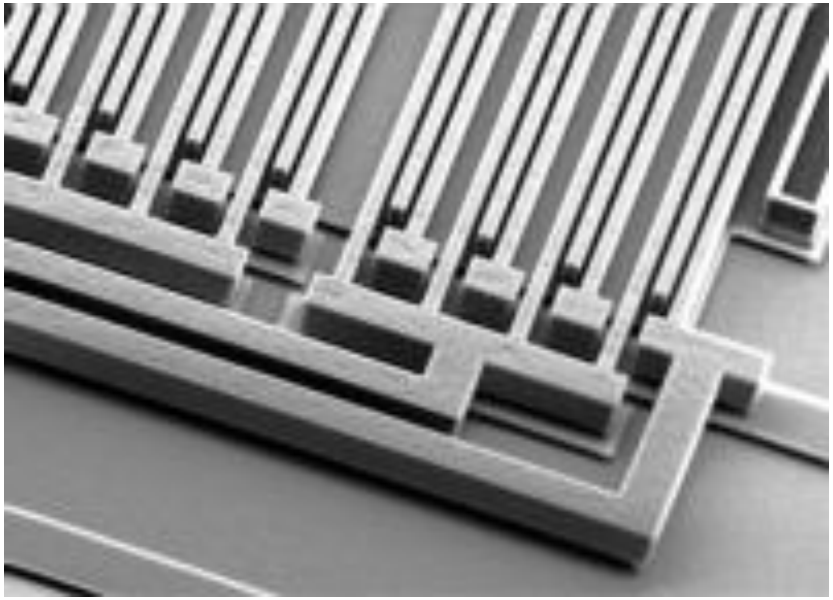


Low Cost Electronics (Jet-Printed)

CambridgeNanoTech
Simply ALD

MEMS – ALD is a good fit…

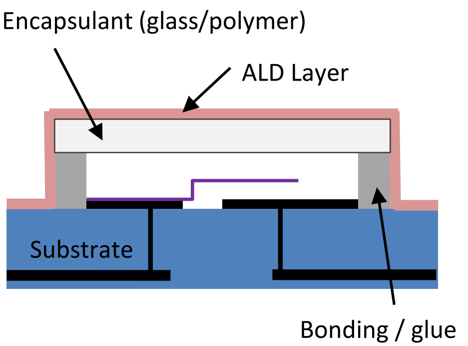
Micro Electromechanical Systems



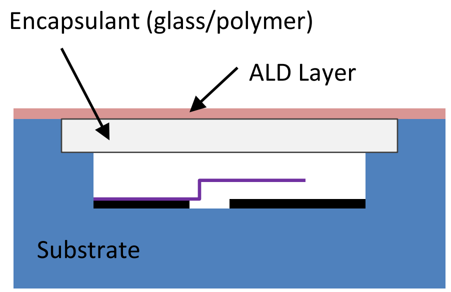
- Billion dollar market - CURRENTLY
- Pressure sensors, accelerometers, blood pressure, displays…
- ALD MEMS applications: conformal dielectric, lubrication / anti-stiction, anti-wear, thermionic layer, encapsulation

MEMS - Encapsulation Films

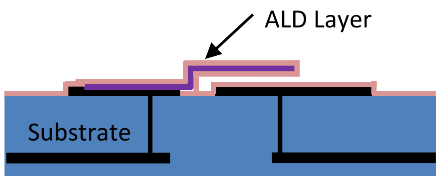
Different Types of Hermetic Sealing



ALD Layer acts as supplement to ***bonding*** layer



ALD Layer acts as supplement to ***encapsulating*** layer



ALD Layer is the ***encapsulating*** blanket layer

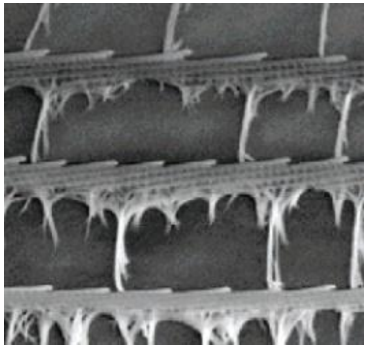
- Different type of hermetic sealing based on different device architecture
- ALD "blanket" layer can act as anti-stiction, dielectric, etc. layer as well as hermetic layer

CambridgeNanoTech
Simply ALD

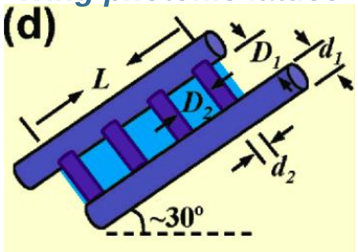
Low Temperature ALD

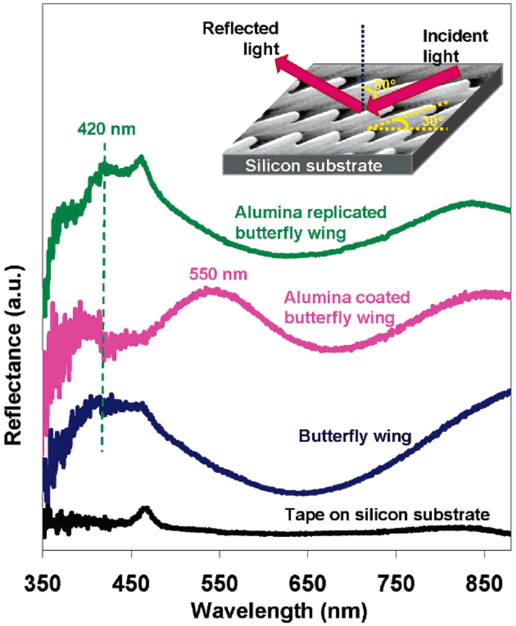
- Some ALD processes can deposit films < 150°C: Al_2O_3, HfO_2, SiO_2, TiO_2, ZnO, ZrO_2, Ta_2O_5, SnO_2, Nb_2O_5, MgO, In_2O_3
- With plasma, also add, Pt, Ru, Pd, Cu….
- Ideal for merging organics with inorganics
- Compatible with photoresist, plastics, biomaterials

Morpho Peleides **butterfly**



Wing photonic lattice



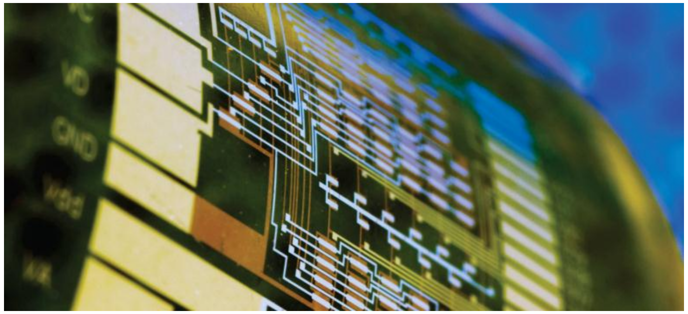


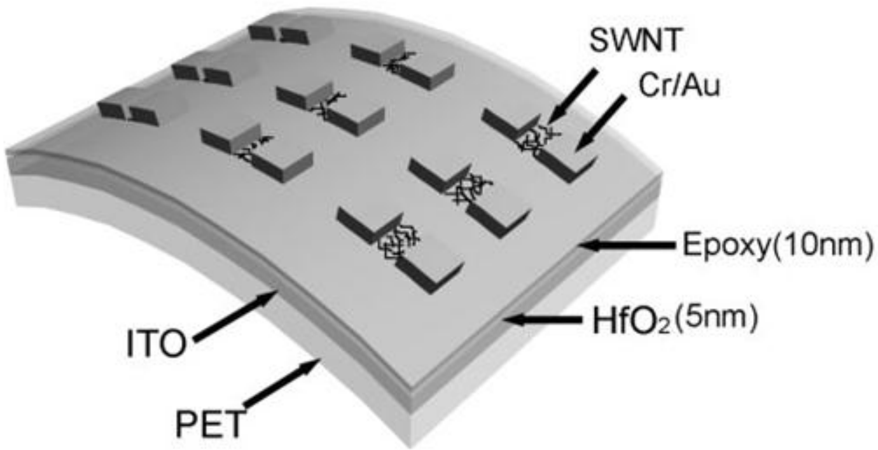
Huang J. Y. *Nano Letters.* **2006**, 6, 2325

CambridgeNanoTech Simply ALD

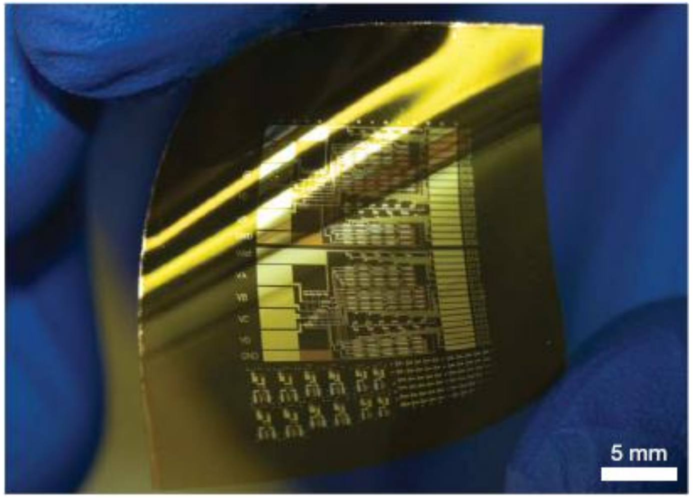
ALD for Flexible Electronics

- High quality HfO_2 gate dielectric, deposited at 100°C
- Low stress film - flexible





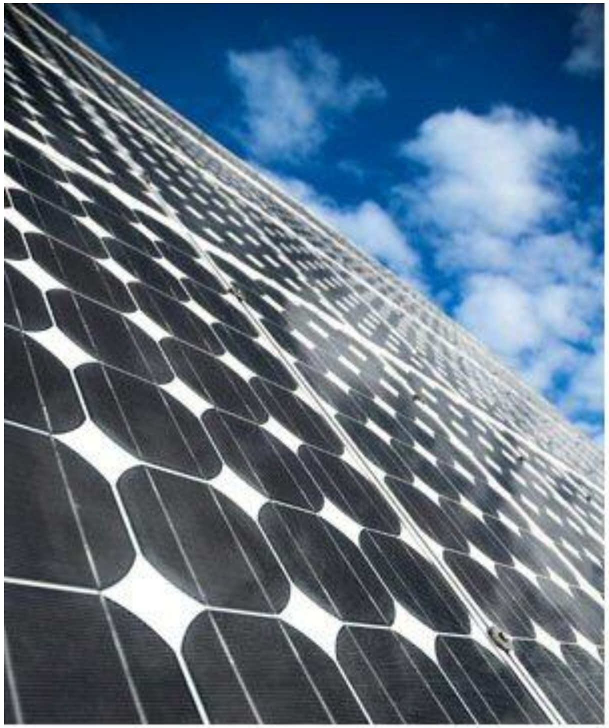
Advanced Functional Materials, ***2006***, *16***,** *2355-2362***.**
Nature, **2008**, *454***,** 495-500**.**



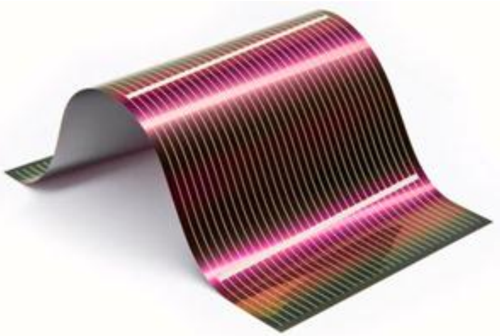
large capacitance (up to ca. 330 nF cm^{-2}), and low leakage current (ca. 10^{-8} A cm^{-2})

ALD – Solar Cells

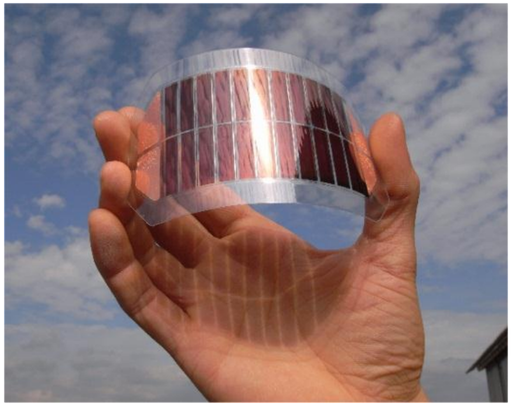
Silicon

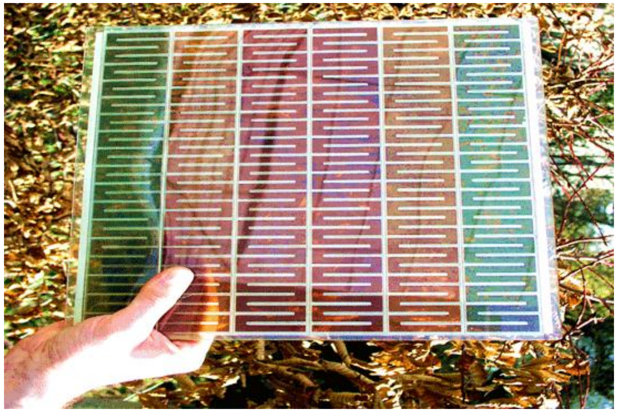


Thin Film

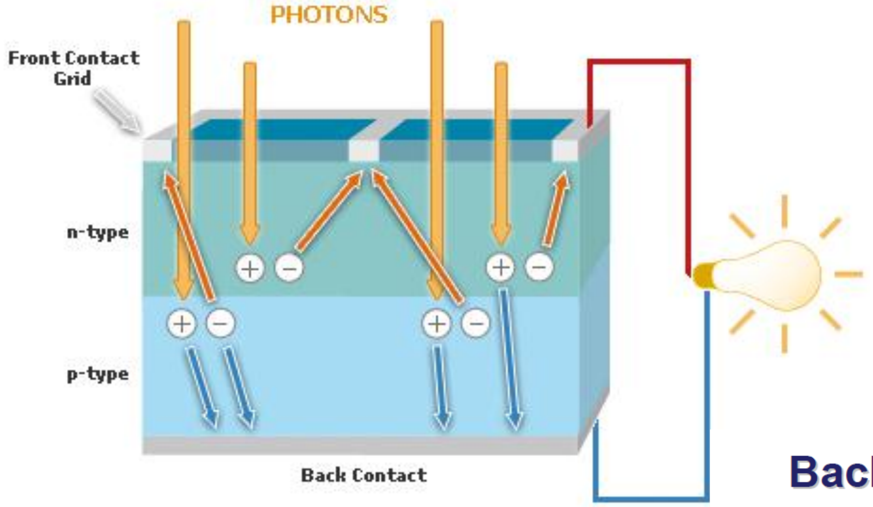


Organic PV





Silicon Solar Cell Passivation

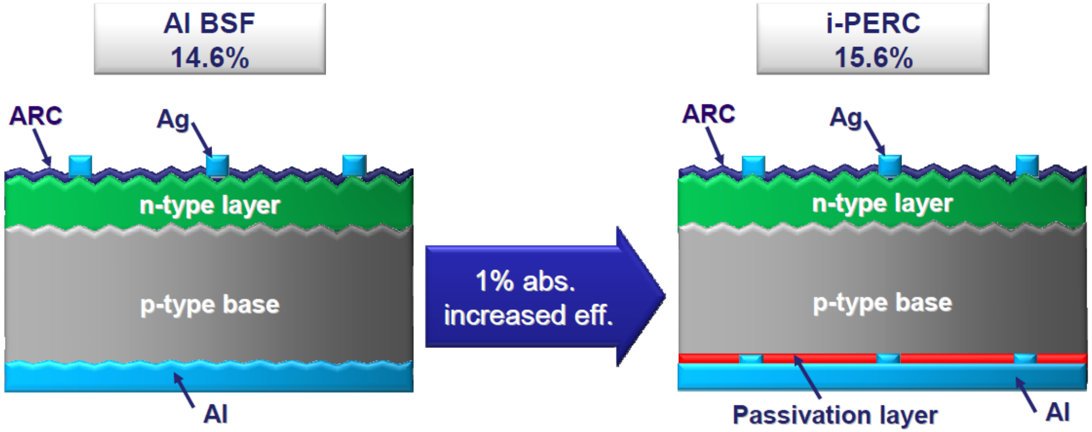


ALD Al_2O_3 passivation removes defects of dangling bonds on Si

Helps prevent surface recombination

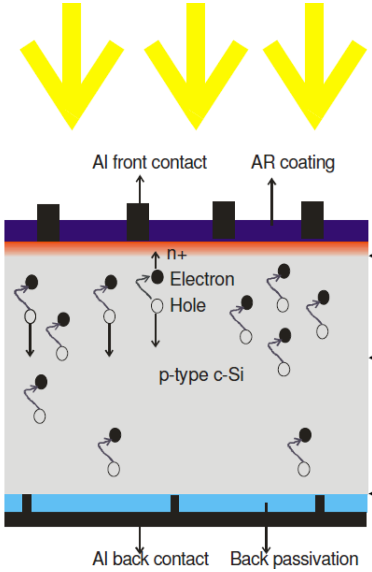
Backside passivation of Si solar cells

- Al_2O_3 acts as a *surface passivation layer* in silicon solar cells*
  → Higher efficiency → Thinner wafers → lower costs/W_p



Passivated Emitter and Rear Cell (PERC), 140 EFG,140 µm, 100 cm²
(imec, Crystal Clear, EUPVSEC 2009)

Silicon Solar Cell Passivation



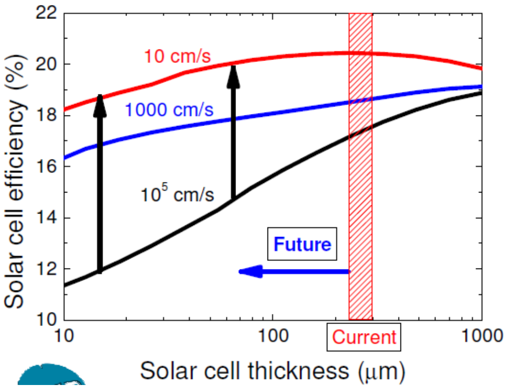
- c-Si solar cell is a "diffusion" type solar cell with current collection at front and back contact
- High electron-hole pair lifetime τ_{eff} is essential to allow diffusion to the surfaces

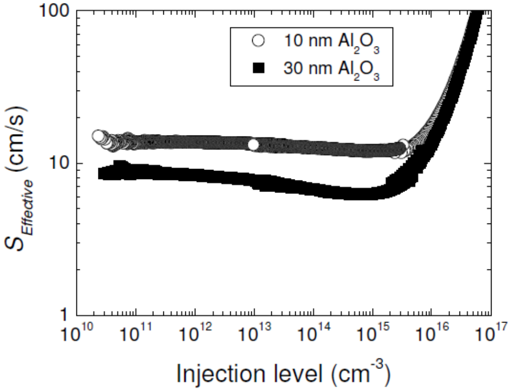
Recombination in emitter and at surface

Recombination in bulk

Recombination at back surface

- Surface passivation on the back is essential when decreasing solar cell thickness
- Current technology (Al BSF) yields only ~1000 cm/s on the back side!



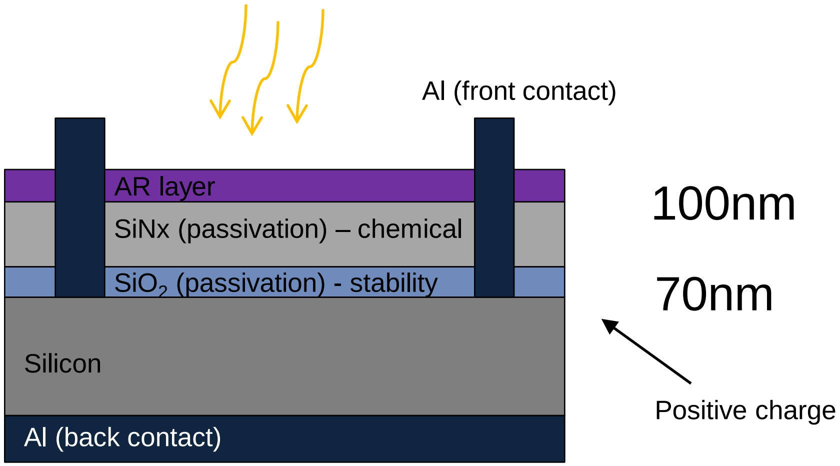


- c-Si surface can effectively be passivated by Al_2O_3
- Al_2O_3 exhibits low interface density
- Al_2O_3 has a high amount of negative built-in charge (~10^{12}-10^{13} cm^{-2})

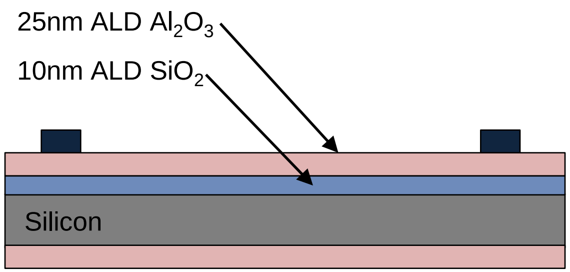
CambridgeNanoTech
Simply ALD

Silicon Solar Cells

Traditional Silicon



With ALD



- Highly doped p-type or n-type c-Silicon solar cells
- Chemical passivation (interface trap density) – dangling bonds (SiO_2 or SiN_x passivates)
- Field effect passivation (negative fixed charge in Al_2O_3) passivates SiO- at the Si-SiO_2

Thin Film Solar Cells

- Thin film solar cells can have higher efficiencies than silicon cells >28% for single junction in natural sunlight
- Substrate can also be metal foil, polymer, glass – cheaper than c-Si
- **But there are some issues….**

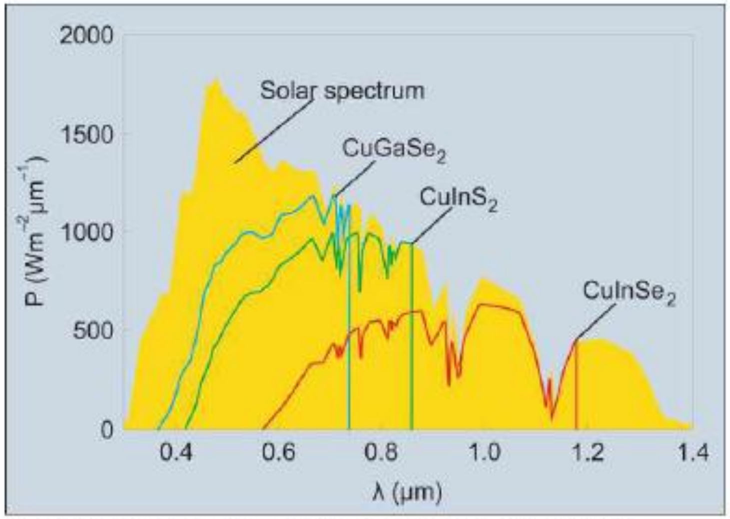
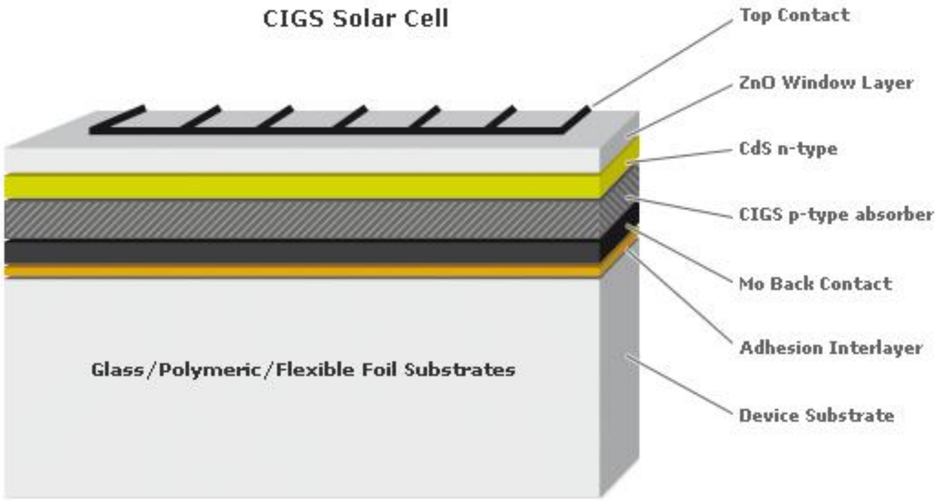
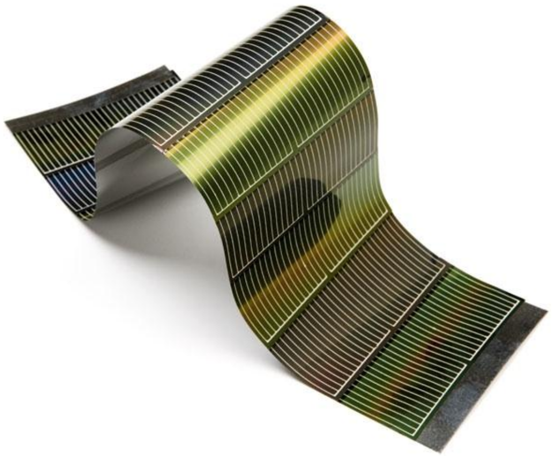


Figure 10. Solar spectrum and response of CIGS materials, showing possibilities for multi-junction solar cells.





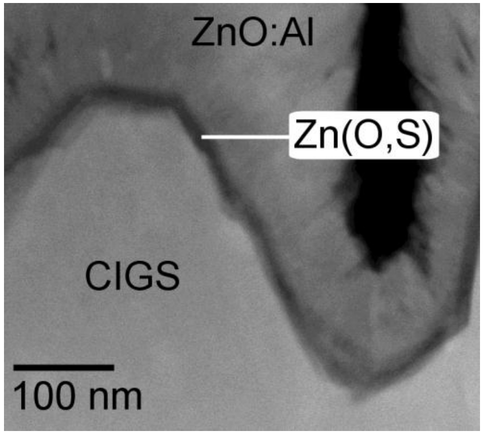
CambridgeNanoTech
Simply ALD

Thin Film Solar Cells

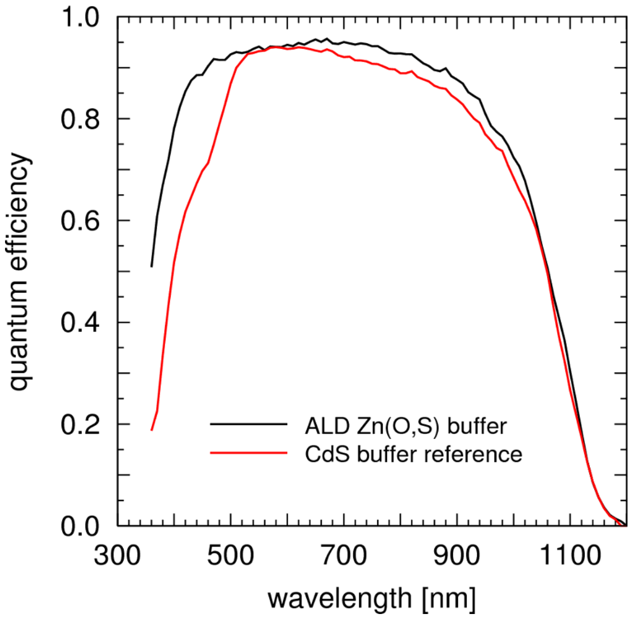
Key feature: Absorber / Buffer / TCO combination determine spectral capture range

ALD Insertion points:

- TCO layer
- Encapsulation
- **buffer layer: replacement for CdS**



Cross section TEM image of a CIGS solar cell with ALD grown Zn(O,S) buffer layer. The buffer layer is the dark band between the CIGS grains and the columnar ZnO:Al front contact layer. The dark area to the right is a void.

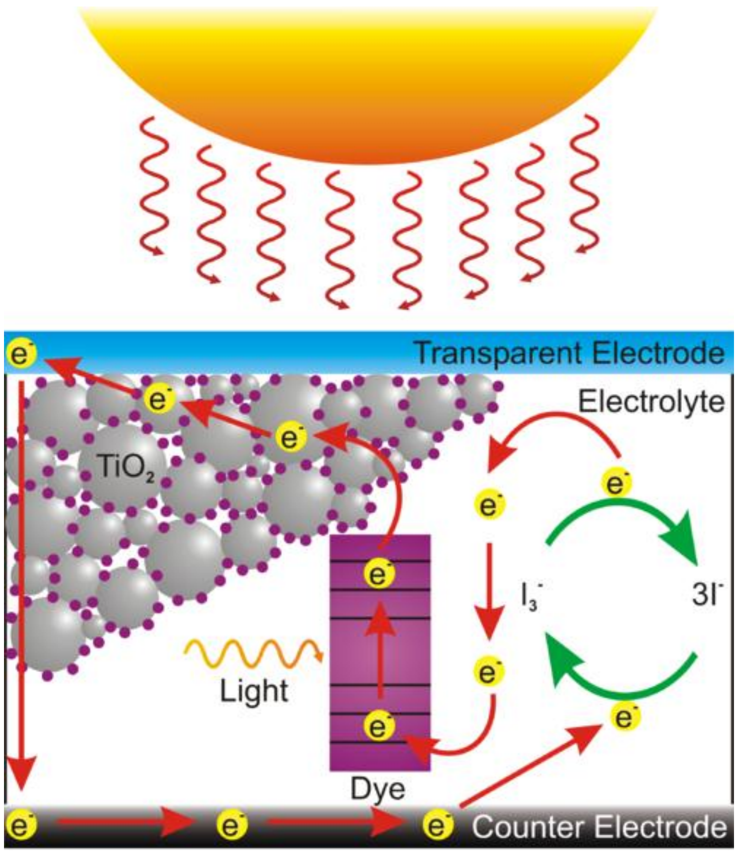


Quantum efficiency measurement for a cell with ALD Zn(O,S) buffer layer and a reference cell with CdS buffer.

CambridgeNanoTech
Simply ALD

Dye Sensitized Solar Cells (DSSC)

Dye-Sensitized Solar Cell Schematic



DSSCs still have comparably low efficiency compared to thin film / c-Si solar cells

Many interfaces require optimization in DSSCs:

How can ALD help?

Tune interface of dye/photoanode:

- suppress recombination

Prasittichai, C.; Hupp, J. T. *J Phys Chem Lett.* **2010**, *1*, 1611.
Bills, B., Shanmugam, M., et a. MRS S*ymp. Proc. 2010,* vol. 1260.

Novel photoanode

Hamann, T. W.; Martinson, A. B. F.;Elam, J. W.; Pellin, M. J.; Hupp, J. T *J. Phys Chem. C*. **2008**, *112*, 10303

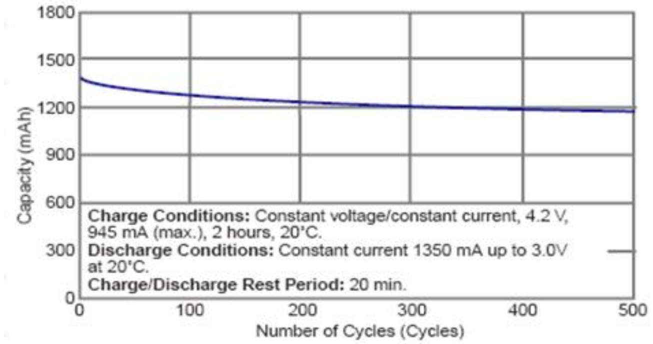
Novel structure to minimize electron transfer distance

Silica Aerogel - Li, T. C., et al. *J Phys Chem. C*. **2011**, *115*, 11257-11264.
AAOs - Martinson, A. B. F., Hamann, T. W., Pellin, M. J., & Hupp, J. T. *Chem. Euro J*. **2008**, *14*, 445

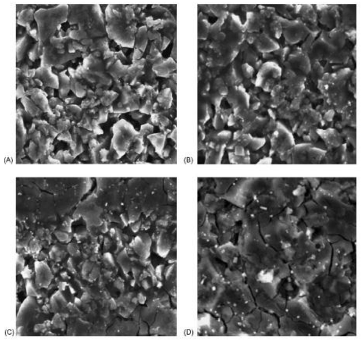
CambridgeNanoTech
Simply ALD

Current Li-ion Battery Limitations

Lithium ion batteries are promising but current issues prevent need to be addressed



1. Specific charge capacity decreases rapidly with number of charge-discharge cycles



Continuous fast charging alters microstructure of cathode/anode

2. Slow charge up time
   - Fast charge or discharge can result in damage to the electrode material

3. Safety issues with liquid electrolyte being exposed to
   - Lithium electrolyte is pyrophoric

4. Low power density
   - Large batteries are cumbersome for increasingly smaller consumer devices

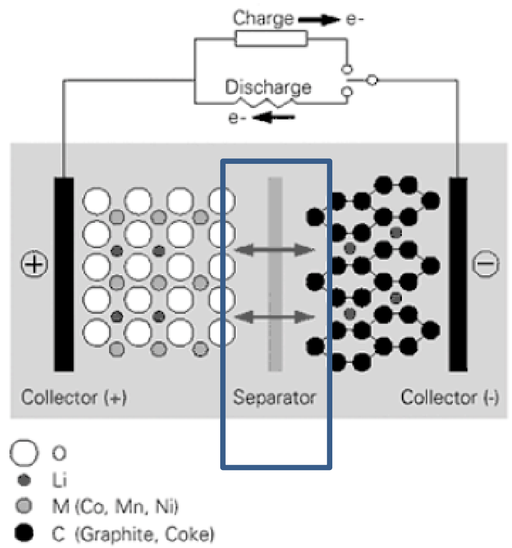
CambridgeNanoTech
Simply ALD

Li Ion Batteries

Can ALD help increase cycle lifetime?

Cathode materials:

$LiCoO_2$
$LiMn_2O_4$
$LiNiO_2$
$LiFePO_4$
V_2O_5
MnO_2
etc.



http://www.varta-automotive.com

Anode materials:

Graphite (LiC_6)
Si
TiO_2
$Li_4Ti_5O_{12}$
Sn_3N_4
etc.

Anode – cathode separator is a thin plastic membrane coated with ceramic paste;

- typically 30-40% of total cost of Li-ion battery,
- Failure mechanism - loss of charge capacity due to fouling of membrane
- Li ions cannot effectively move across separator after cycling

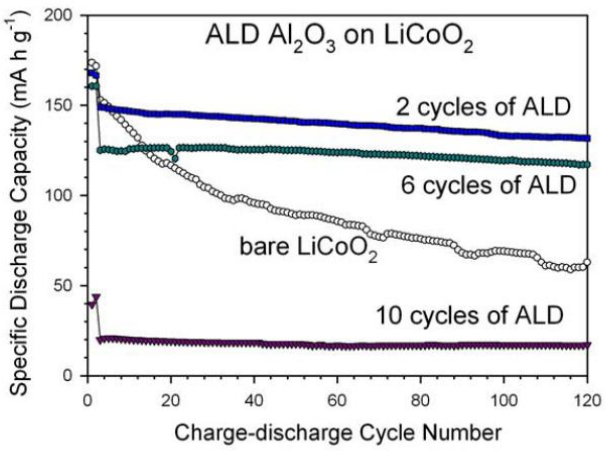
Can ALD layers replace the ceramic paste in the separator to reduce fouling / plugging?

Li Ion Batteries

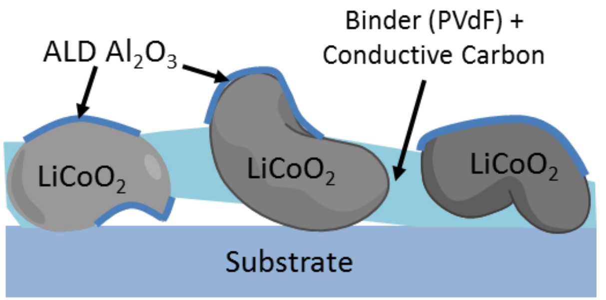
ALD layers help to improve long term specific charge capacity

- Prevent corrosion of cathode with thin Al_2O_3 layer

ALD Al_2O_3 films (2-8 cycles) improve the capacity retention of cathode material, $LiCoO_2$,from 45% to 89% after repeated cycling



Y.S Yung et al. *J. Electrochem. Soc.* **2010**, *157*, A75-A81.



Lee, J. T.; Wang, F. M.; Cheng, C. S.; Li, C. C.; Lin, C. H. *Electrochimica Acta* **2010**, *55*, 4002.

Interface engineering is possible by ALD

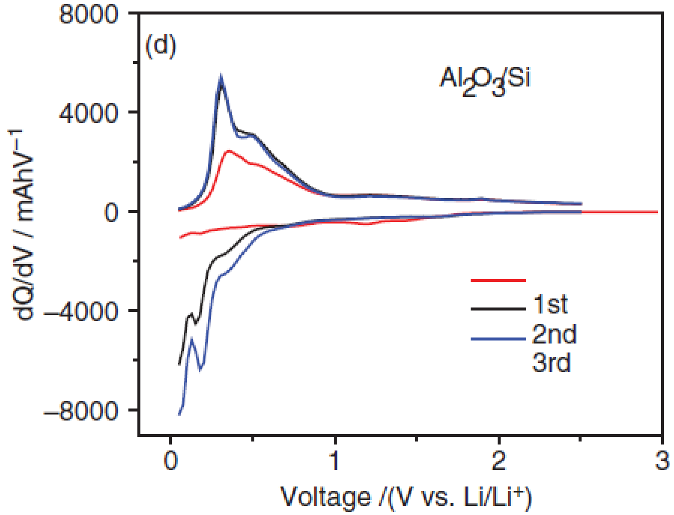
Li Ion Batteries

ALD layers <u>directly</u> improve specific charge capacity by improved performance of cathode

Typically, charge capacity decreases after first charge/discharge cycle.

A few cycles of ALD Al_2O_3 increases charge capacity after first cycle: Formation of thin and stable SEI layer is enhanced by ALD Al_2O_3 - $LiAlO_2$ forms after first charge/discharge cycle; helps to lower energy barrier for Li diffusion into and out of anode

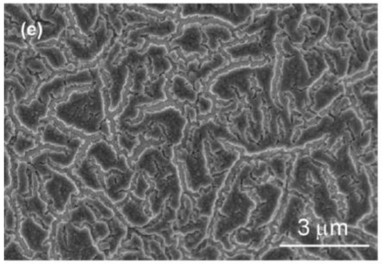
- Al_2O_3 helps to improve mechanical stability as well as corrosion resistance, SEI layer



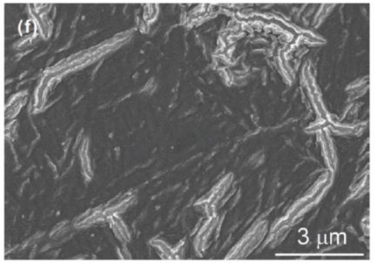
Xiao, X., Lu, P., & Ahn, D. *Adv. Mat*. **2011** *ASAP* doi:10.1002/adma.201101915

Cycled Silicon Anode

Uncoated



ALD Al_2O_3 coated



CambridgeNanoTech Simply ALD

Solar Energy Harvesting

Issues with Solar Energy:

IT GETS DARK AT NIGHT

Can we develop a strategy to harvest energy and store it to do work later?

Photocatalysts for water oxidation

$$H_2O + hv \rightarrow O_2 + H_2$$

Materials need to have the following characteristics:

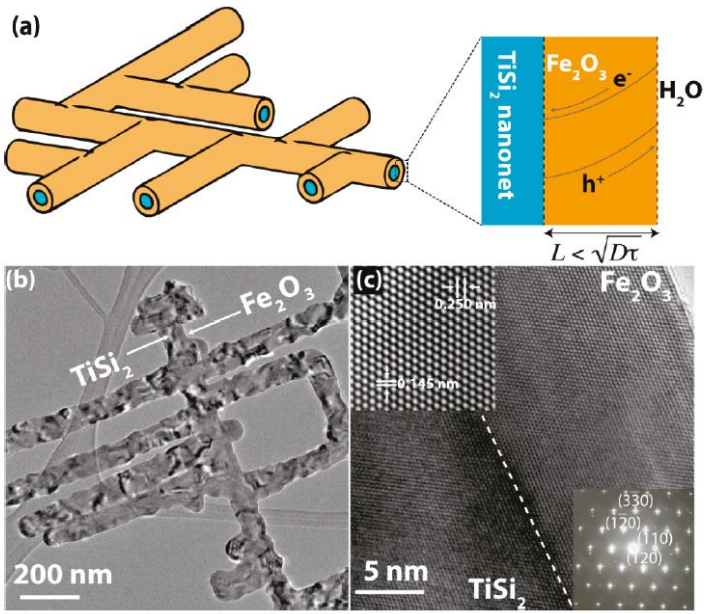
- Strong absorption in the visible range
- Separate charges using absorbed photons
- Collect and transport charges for oxidation reaction

-Difficult to find materials which do all of these things

-Good photoabsorbers (Fe_2O_3, Cu_2O, TiO_2, WO_3) have short charge diffusion lengths

ALD Photocathodes

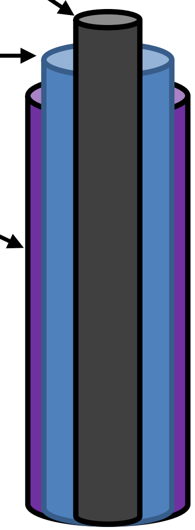
Use nanostructures to create new materials: overcome charge diffusion issues



Charge collector – TiS_2

ALD deposited Photocathode

Oxygen evolving catalyst (optional)
MnO_x x = 2-5



Photocurrent of 2.7 mA/cm^2 using Fe_2O_3; quantum efficiency 46% at λ = 400 nm (without OEC)

Fe_2O_3 - Lin, Y.; Zhou, S.; Sheehan, S. W.; Wang, D. *J. Am. Chem. Soc*. **2011**, 1*33*(8), 2398-401
WO_3 - Liu, R., Lin, Y., Chou, L.-Y., Sheehan, S. W., He, W., Zhang, F., et al. *Angew. Chem. Int. Ed.* **2011**, *3*(3), 499-502.
TiO_2 - Lin, Y., Zhou, S., Liu, X., Sheehan, S., & Wang, D. *J. Am. Chem. Soc.* **2009**, *131*(8), 2772-3.

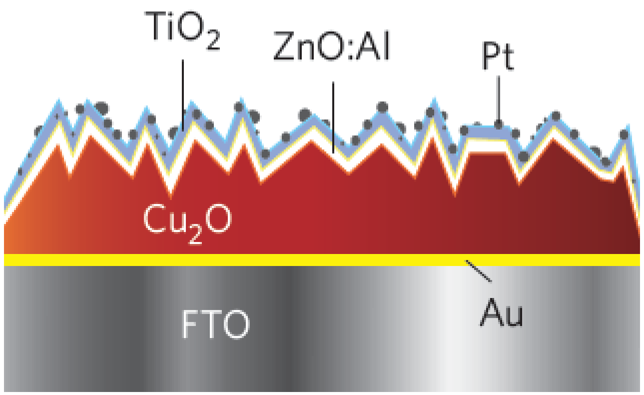
ALD Improved Photocatalysts

ALD layers used for interface control:

- repairs defects in electrodeposited Cu_2O surface;
- prevents degradation to cathode material;
- improves performance of device

ALD TiO_2 helps prevent corrosion /degradation of Cu_2O
ALD ZnO:Al films used as photon extraction layer

Highest recorded photo current 7.6 mA / cm^2
Photon-to-current efficiency was 40% between 350 and 480 nm

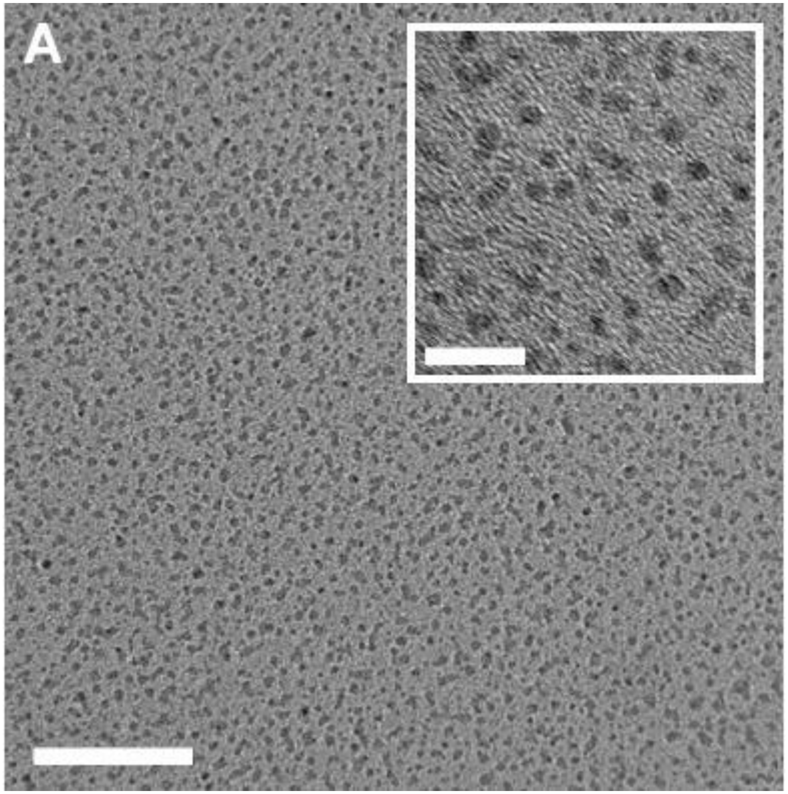


Paracchino, A. Laporte, V.; Sivula, K.; Grätezel, M.; Thimsen, E. *Nat. Mater* **2011**, *10*, 457.

Pt nanodot (hydrogen evolving catalyst) also possible by ALD; as are other layers i.e.) MnO_x

Ru Nucleation - Nanodots

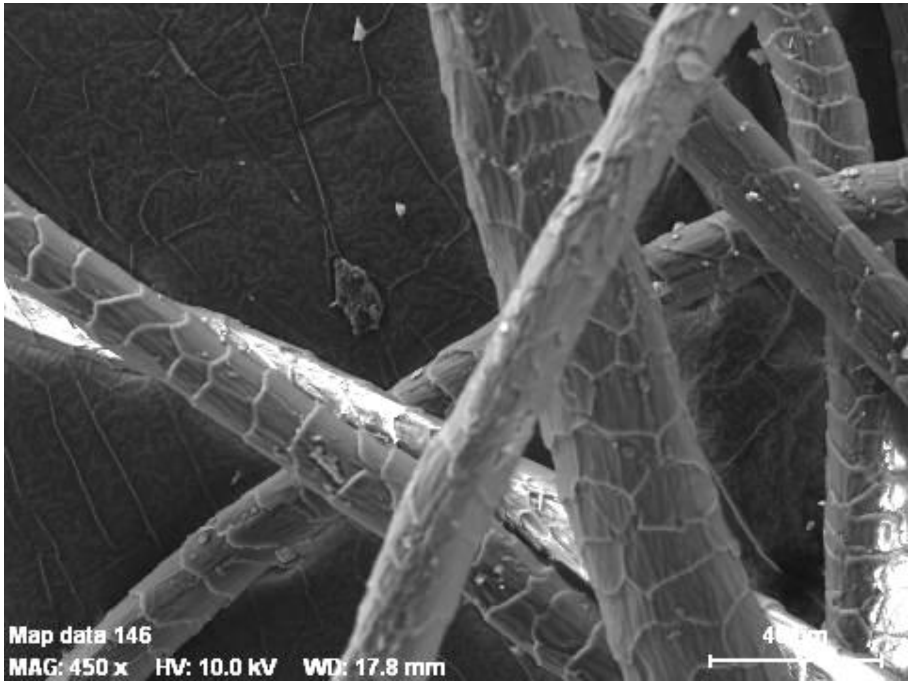
- Nucleation of Ru is substrate dependent
- Allows for formation of nanodots; diameters of ~1-2nm, 5-10 atoms across
- Takes advantage of slow nucleation of Ru on oxide
- film will become continuous with enough cycles



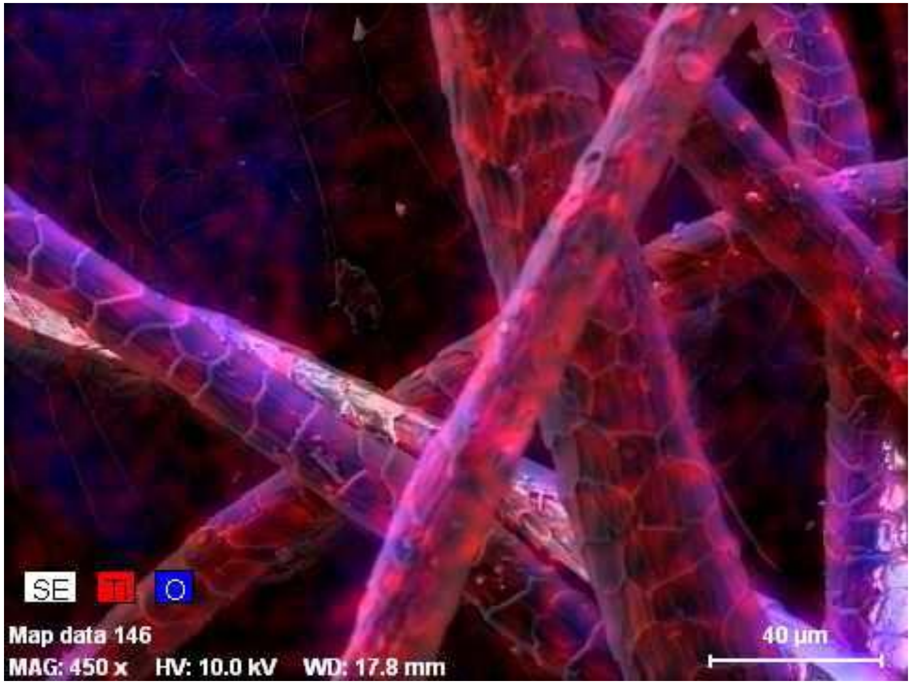
40nm scale bar. 10nm in inset

Interesting applications for catalysis – controlled "active sites" with size distribution

Textiles



Wool fabric coated with ALD TiO_2

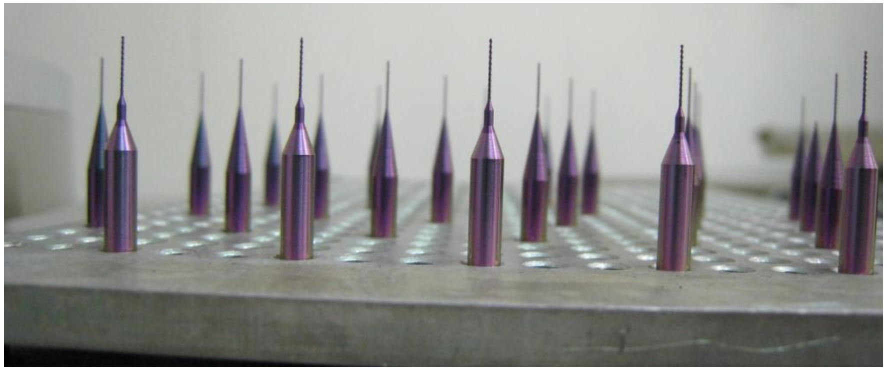


EDS X-ray map of the wool

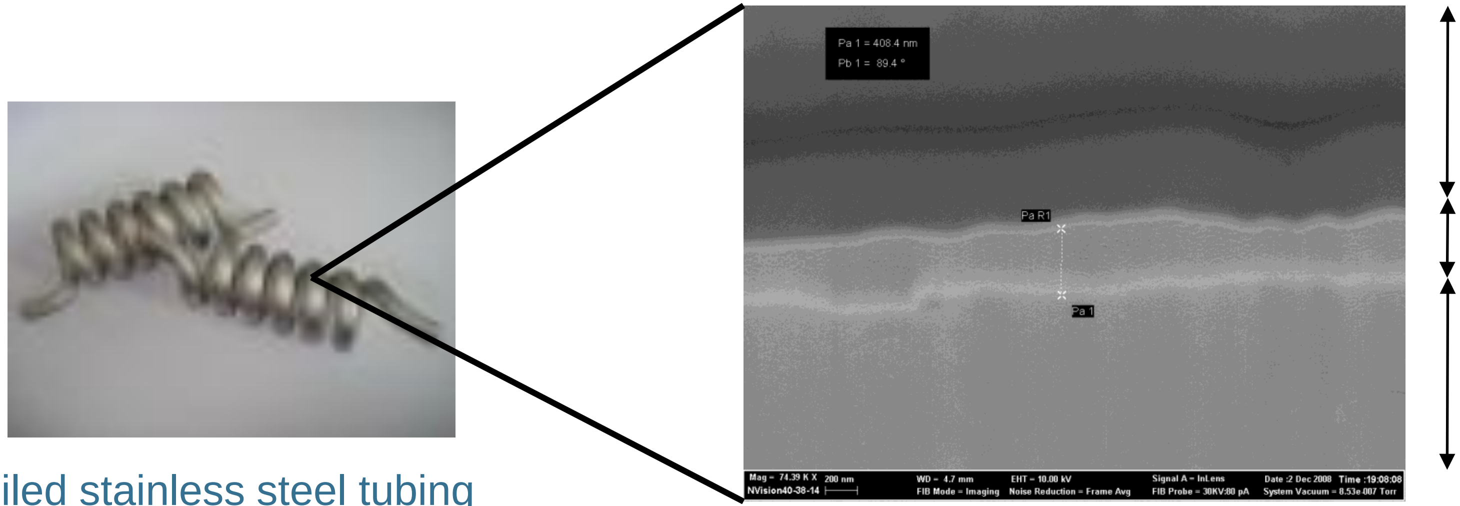
- Spill resistant fabrics – SAMs hydrophobic coatings
- High moisture absorbancy fabric (sportswear) – SAMs Hydrophilic coating
- Abrasion resistant fabrics – Al_2O_3 coatings
- Anti-microbial coatings – TiO_2 coating

CambridgeNanoTech
Simply ALD

Macroscopic Coatings



Drill bits with ZrO_2 coatings



Protective layer of Carbon

Conformal Ru coating

Stainless Steel

Coiled stainless steel tubing

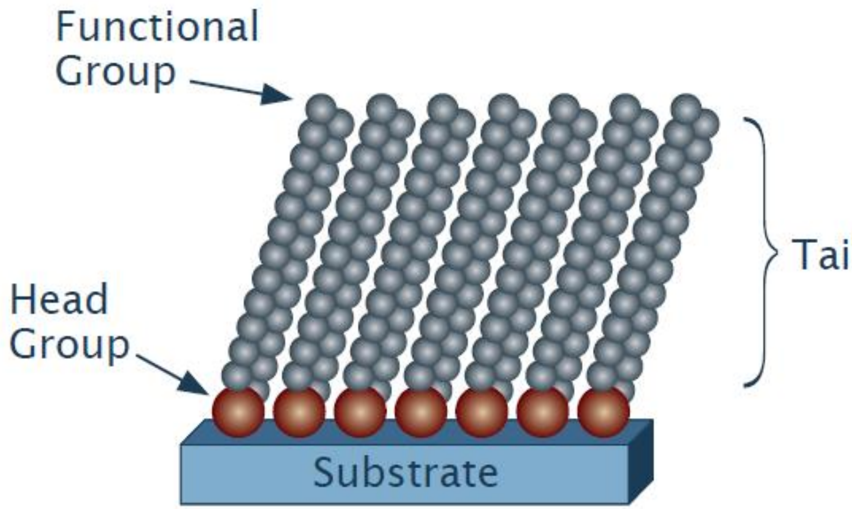
FIB Cross-section of interior coated with ALD deposited Ru

CambridgeNanoTech
Simply ALD

MLD: SAMs: 2-D Self-Assembly

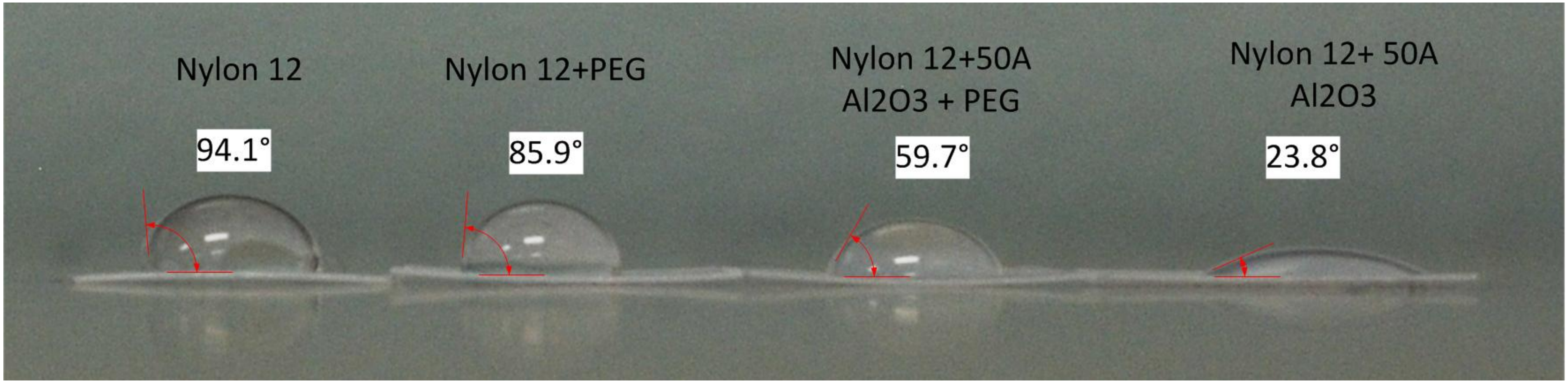
- Self-assembly in liquid or vapor phase driven by amphiphilic character of the molecules
- Ordered molecular 2D assemblies formed spontaneously by the chemisorption of the head group to a substrate.

- Head group
  - Affinity to substrate to induce chemisorbed surface reactions
  - High energy chemical bound (100 kJ/mol) provides molecular stability (thermal, chemical, biological)
- Tail group
  - Closed-packed structure driven by Van der Waals interaction between alkyl chains
- Functional group
  - Defines properties of monolayer, e.g., hydrophobicity/hydrophilicity, affinity to anchor with biological entities



PEG hydrophilic coating on Nylon

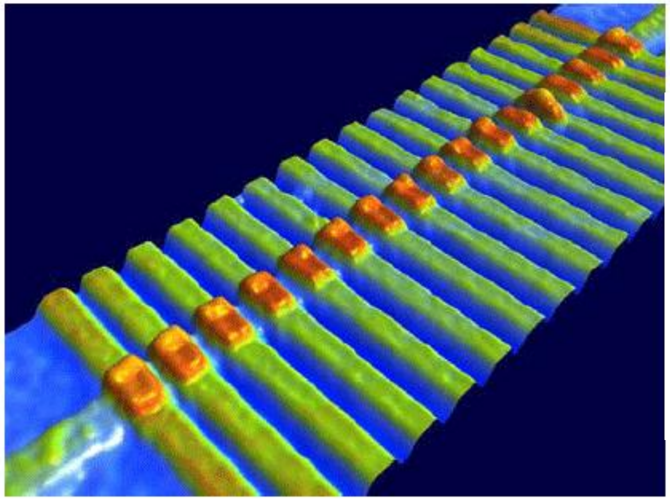
Tuning coating performance by combining ALD and SAMs

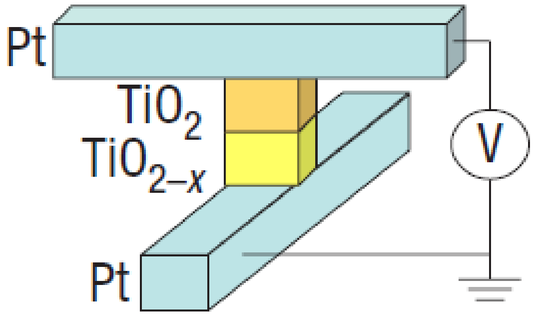


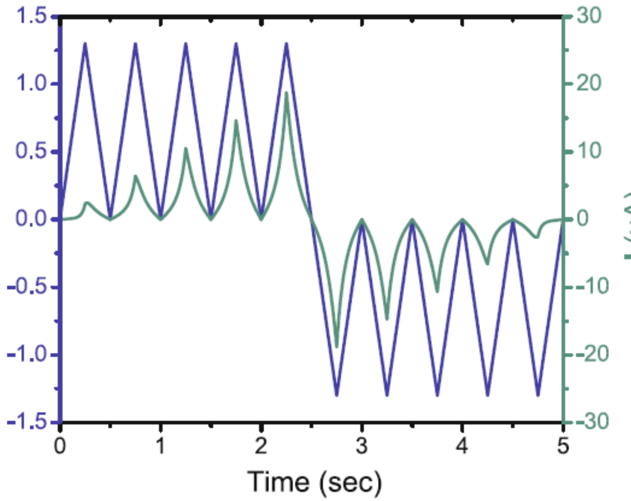
- Precursor: 2Methoxy(polyethyleneoxy)propyl)trimethoxylsilane
- Source @ 100°C, Reactor 50°C
- Sample: Nylon12
- Sample prep: Al_2O_3 ALD seed layer deposited at 50°C
- Result: nylon made more hydrophilic by combination of ALD+ polyethylene glycol coating

CambridgeNanoTech
Simply ALD

ALD for Memristor







- No energy required to store data
- 3-D structure (can be stacked on top of each other)
- Memristive material changes states (based on oxygen vacancies for oxides)
- Many different logic states: not just 0:1

Different Oxygen Vacancies: Different Logic States

0:	MO_x
1:	$MO_{x-0.5}$
2:	MO_{x-1}
3:	$MO_{x-1.5}$
4:	MO_{x-2}

ALD Memristive materials: HfO_2, TiO_2, V_2O_5, WO_3, Cu_2S

Summary

- Interest in ALD remains strong from the microelectronics industry
  - High-K gate oxides, metallization, “zero-thickness” barrier layers
  - Novel device structures
  - **Low cost, printed or flexible electronics**
- Applications such as **lighting /displays**, **solar**, energy storage, anti-**corrosion/anti-wear**, biocompatibility are large opportunities for using ALD
- Much research left to be done:
  - Novel precursors for new ALD films
  - Nanolaminates / doped films
  - Plasma-enhanced ALD

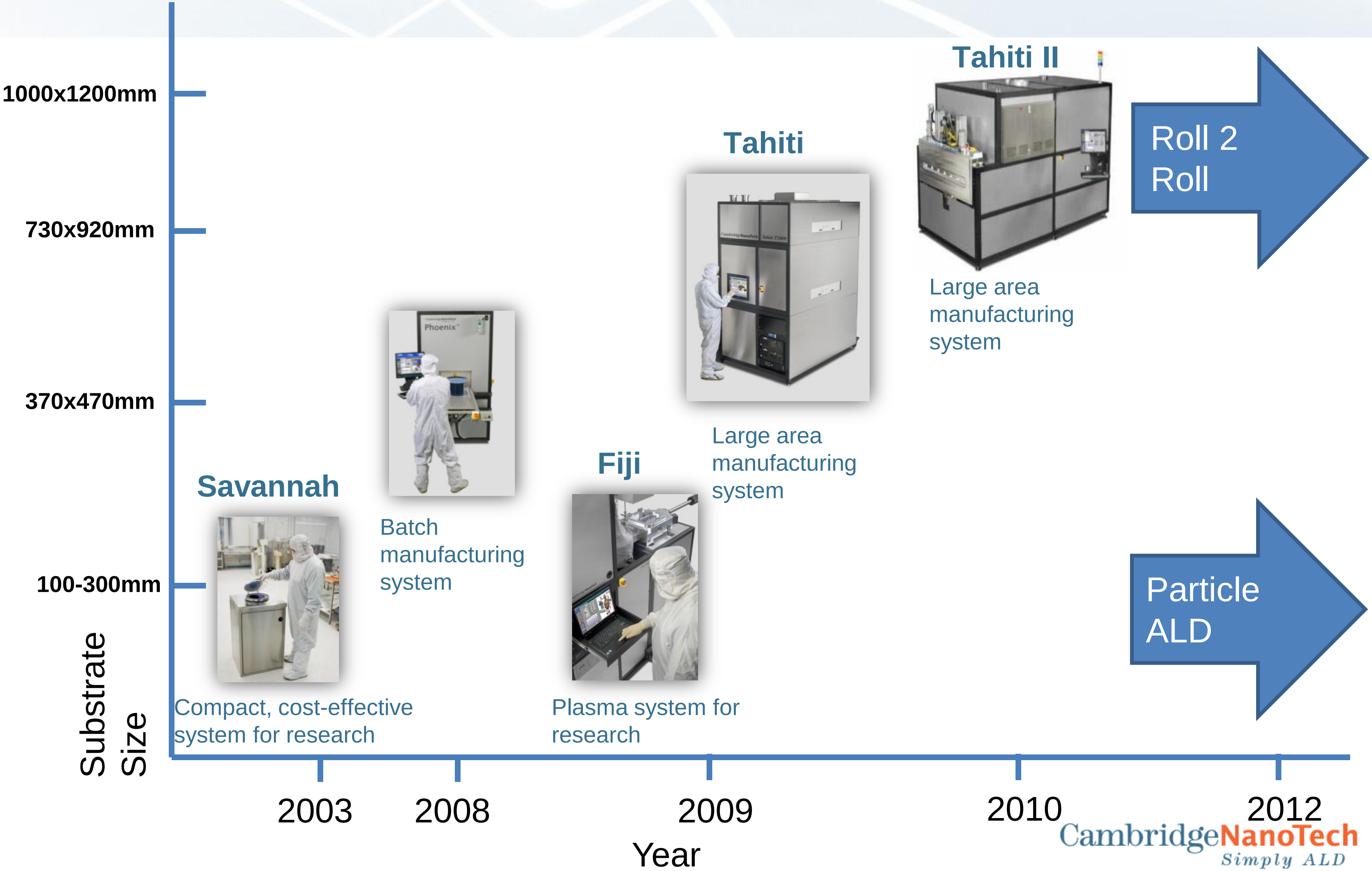
Cambridge NanoTech

- Founded in 2003 by Dr. Jill Becker
- Located in Cambridge, MA
- Grew directly out of Gordon Lab at Harvard University
- Dedicated to advancing the science and technology of ALD
- Multiple ALD product lines serving many applications and industries
- Rapid response to custom applications and projects
- Full staff of Ph.D. research scientists
- Strategic partnerships deliver complete ALD solution

SIGMA-ALDRICH STREM CHEMICALS, INC. MBRAUN Swagelok

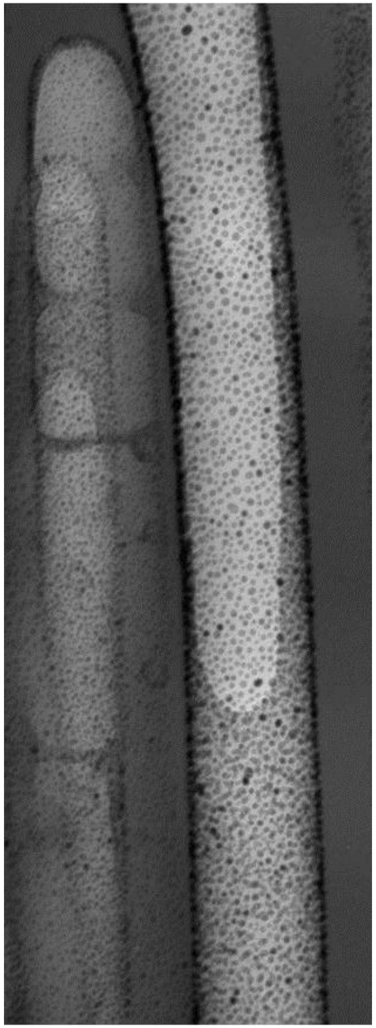
CambridgeNanoTech
Simply ALD

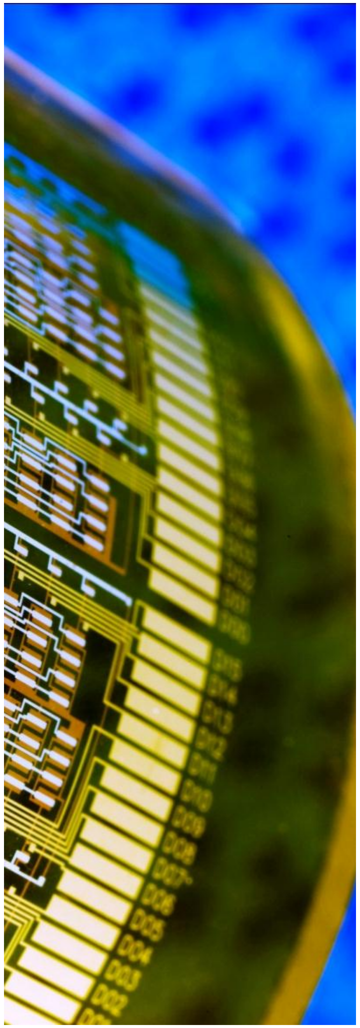
ALD Systems

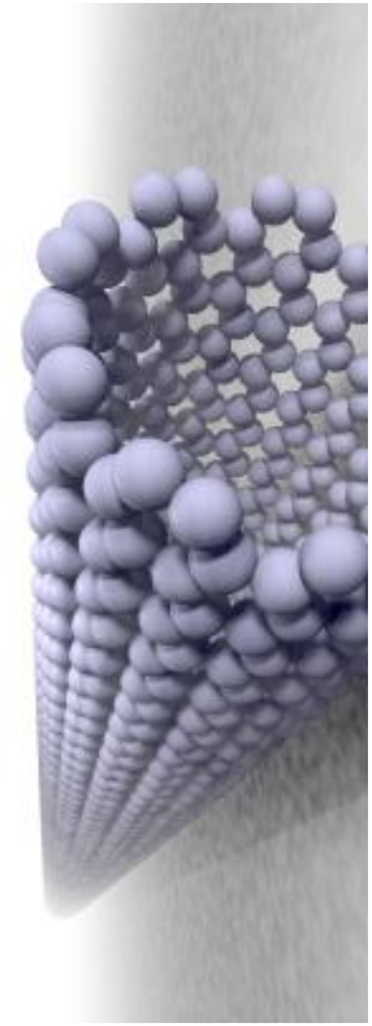


CambridgeNanoTech
Simply ALD

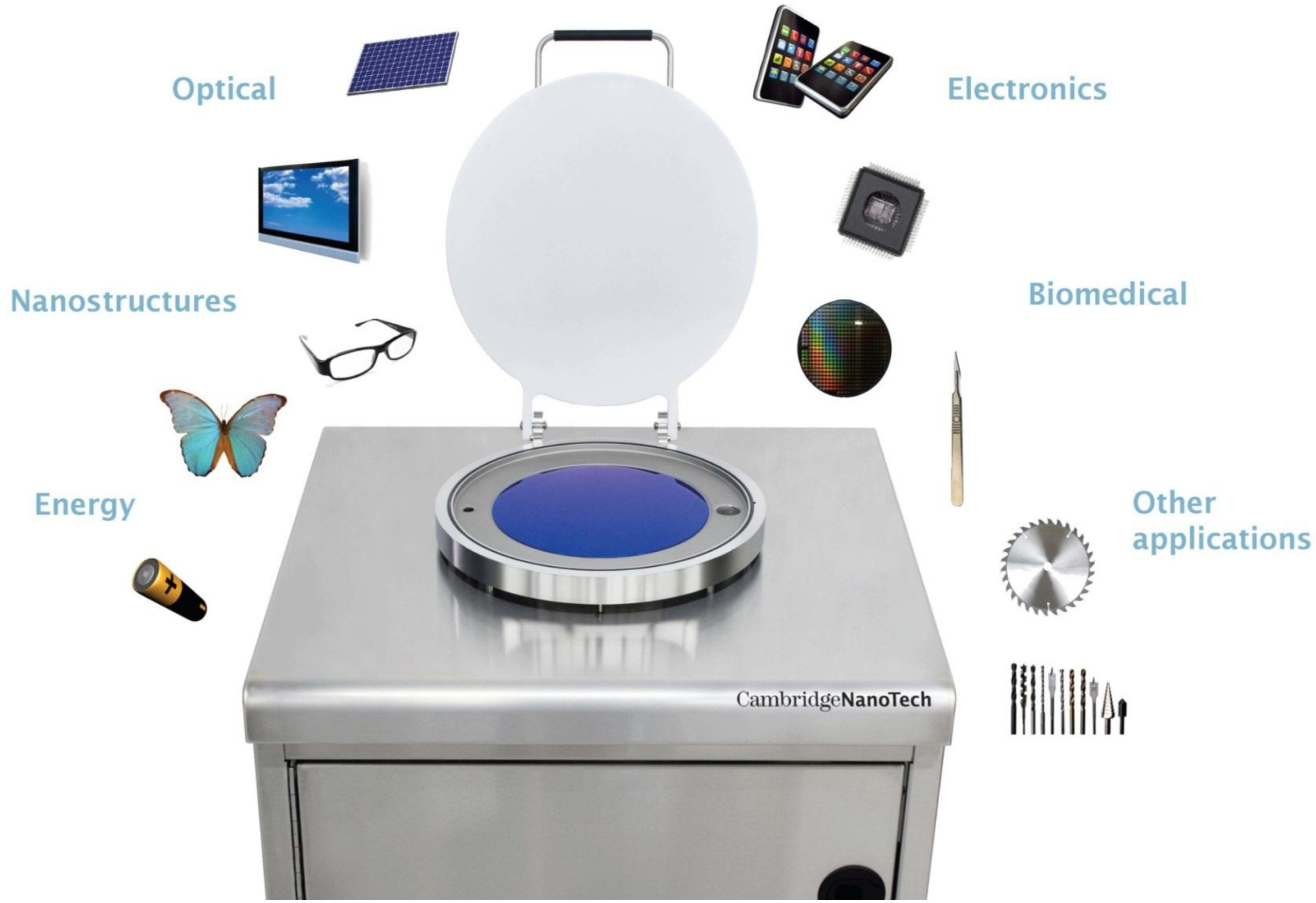
The Promise of ALD







ALD Applications



For application and process help:
support@cambridgenanotech.com

CambridgeNanoTech
Simply ALD