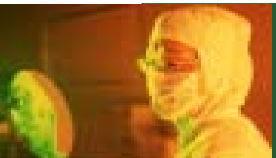
GENUS

ALD Reactor Architectures
ESH Implications

NSF-SRC Network Forum

Tom Seidel, Genus, Inc

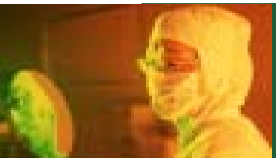
April 24, 2003



Outline

- ALD Introduction
- ALD Reactors
- Process Control
- A Possible ESH Application for ALD

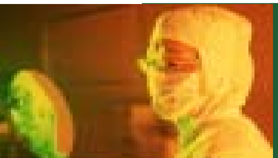
- A Footnote: ISO14000 Certification



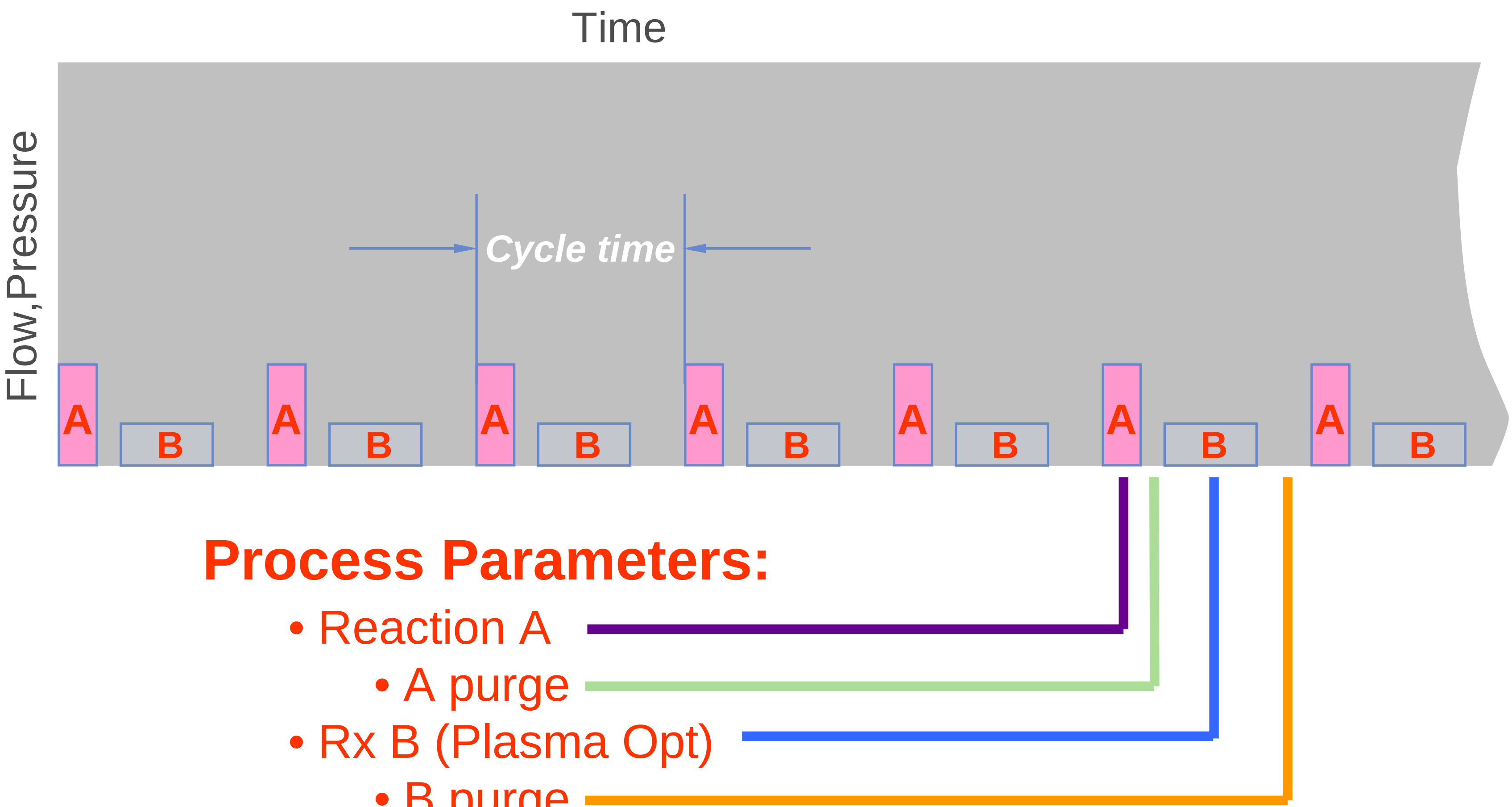
Atomic Layer Deposition

M. Ritala and M. Leskela 2002

- Uses sequential chemisorbed self-limiting and self-passivating “monolayer” reactions on a heated surface
- Reactive Precursors are alternately pulsed onto the surface, separated by an inert purge gas
- Each half-reaction (e.g. for Metal and non-metal) follows exponential or Langmuir kinetics
- Initiation is key to a continuous startup of process
  - e.g surface preparation to achieve: Si-OH

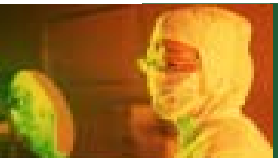


Generic ALD Process Flow



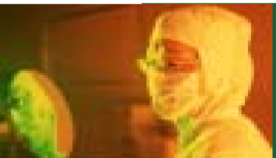
Process Parameters:

- Reaction A
- A purge
- Rx B (Plasma Opt)
- B purge



Varieties of ALD

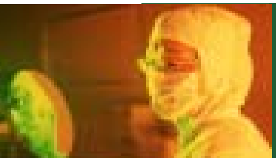
- Thermal
  - $ZnCl_2 + H_2S$ --> $ZnS + 2HCl$ (Suntola, 1989)
  - $WF6 + Si_2H_6$ --> $W + 2SiHF_3 + 2H_2$ (Klaus, 2000)
- Plasma
  - $SiH_2Cl_2 + {}^*H$ --> $Si + HCl$ (Imai, 1994)



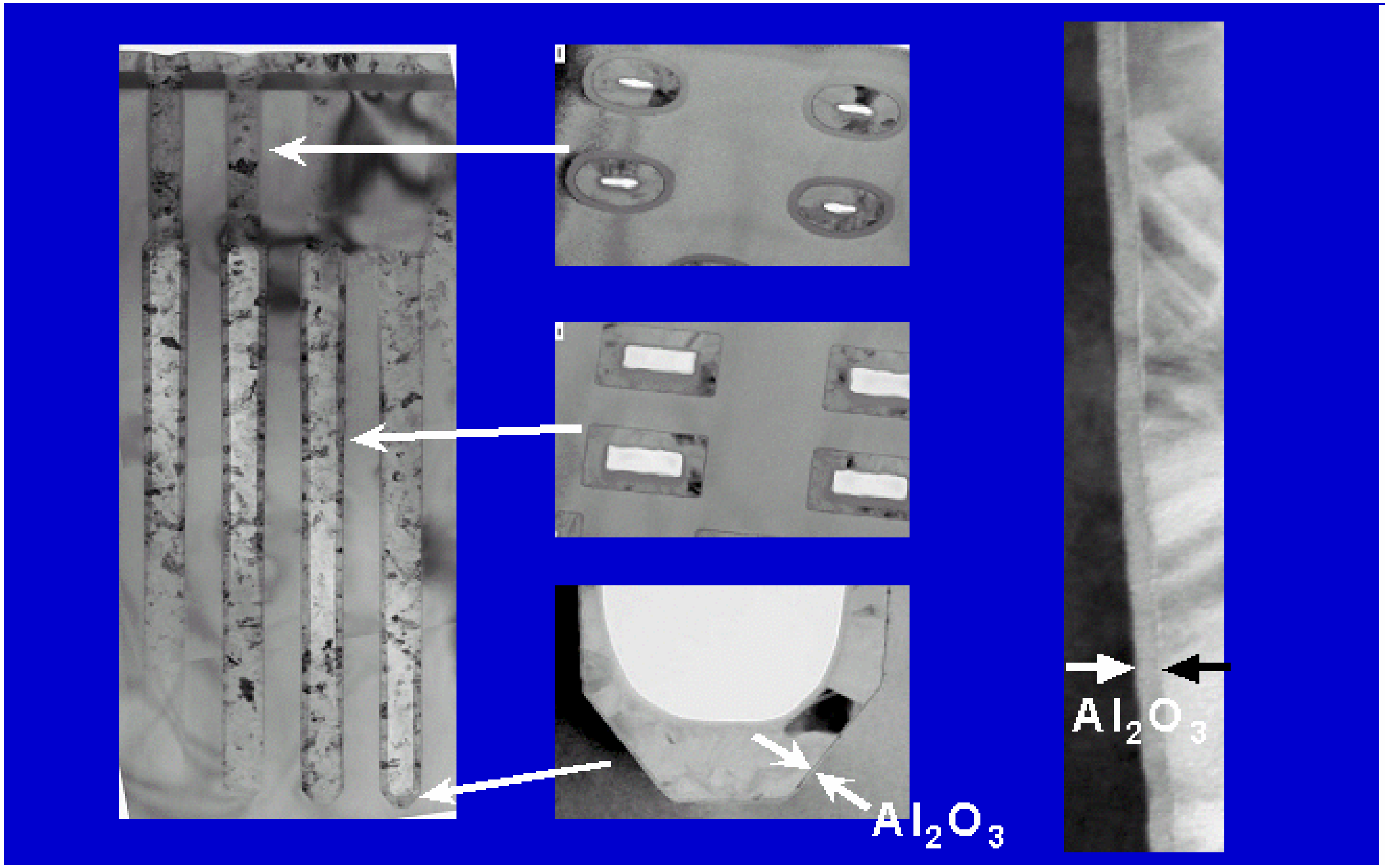
Recent Popular ALD Films

After S. George, 1994

- Al_2O_3 (TMA)
  - $Al\text{-}OH + Al(CH_3)_3 \rightarrow Al\text{-}O\text{-}Al(CH_3)_2 + CH_4$
  - $Al\text{-}O\text{-}Al(CH_3) + HOH \rightarrow Al\text{-}O\text{-}Al\text{-}OH + CH_4$
- HfO_2 (Hafnium Chloride)
  - $Hf\text{-}OH + HfCl_4 \rightarrow Hf\text{-}O\text{-}HfCl_3 + HCl$
  - $Hf\text{-}Cl + HOH \rightarrow Hf\text{-}OH + HCl$



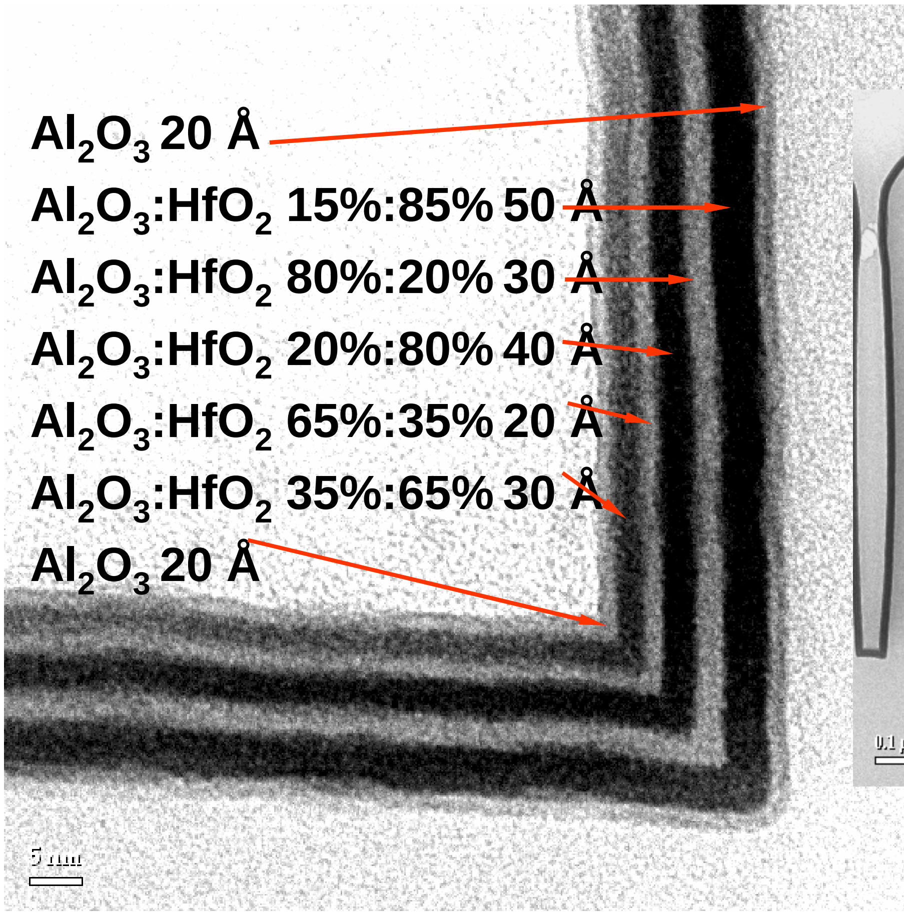
Al_2O_3 in Bottle Shaped Trench
(Courtesy of Infineon, Gutsche, et.al. 2001)

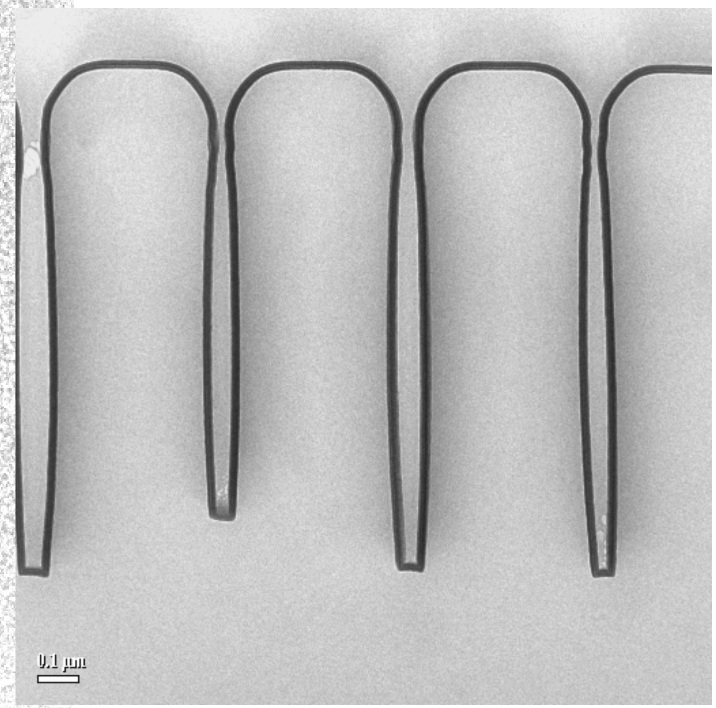


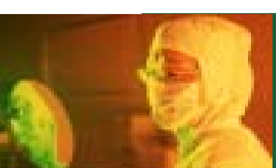
Materials Engineering - Alloys and Stacks

“StrataGem Vision”

(HR TEM is lower right corner of trenches, Sneh,et.al., 2001)





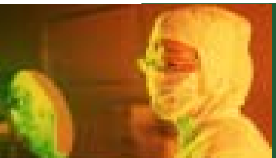


Genus StrataGem^{200} Production System

ALD Reactors

All commercial reactors are now flow type with viscous or transition to molecular flow

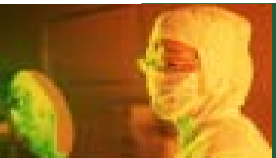
- Single Wafer, Multiwafer
  - Horizontal Flow
  - Vertical Flow
- Batch, Minibatch
  - Horizontal Flow



Reactor Guidelines

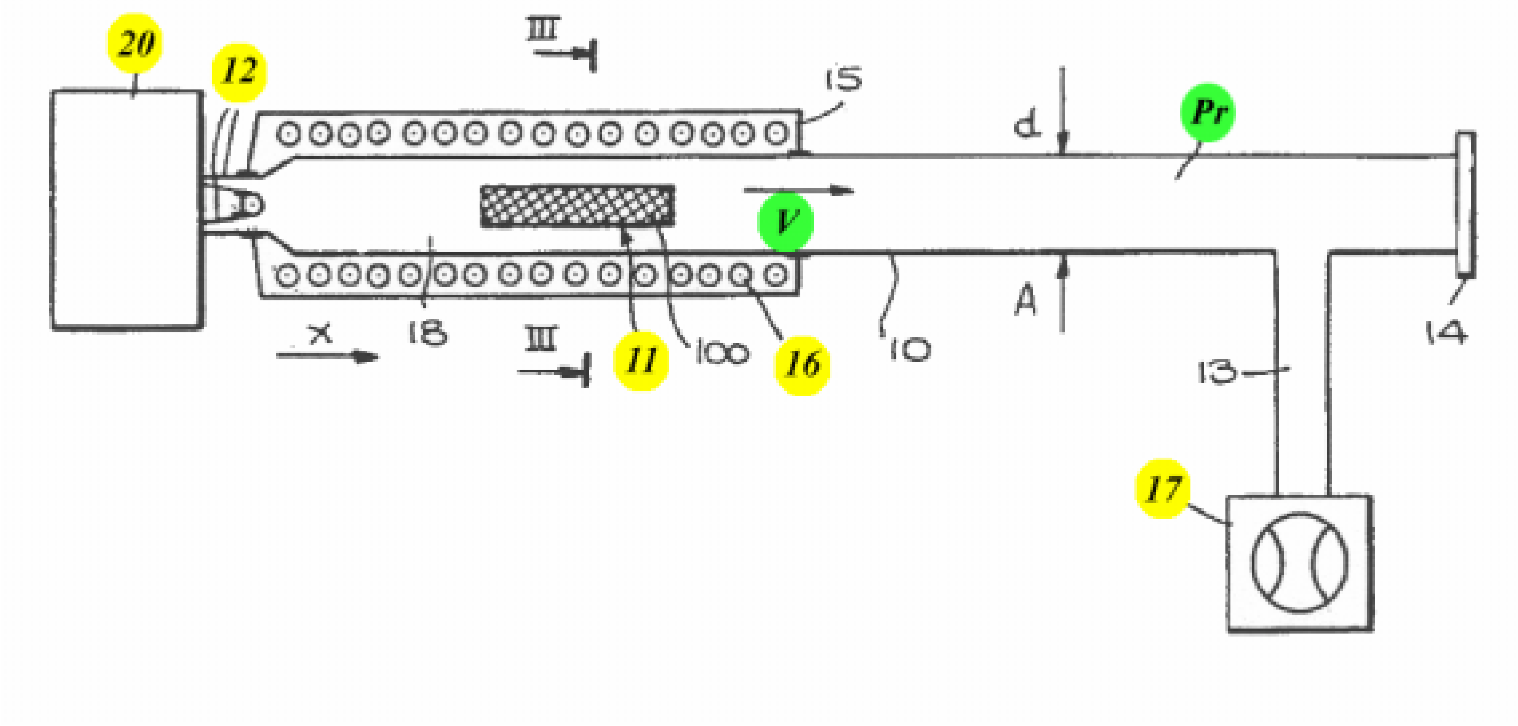
Conventional Wisdom (e.g. Ritala, Sneh...)

- Self-limiting growth ensures precursor fluxes do not need to be uniform over the substrate
- Still, need rapid switching, exposure and purge
- Small Reactor volume and heated walls recommended
- Growth rate (Å/cycle) and ~few seconds/cycle ok for 50Å films (15wph)



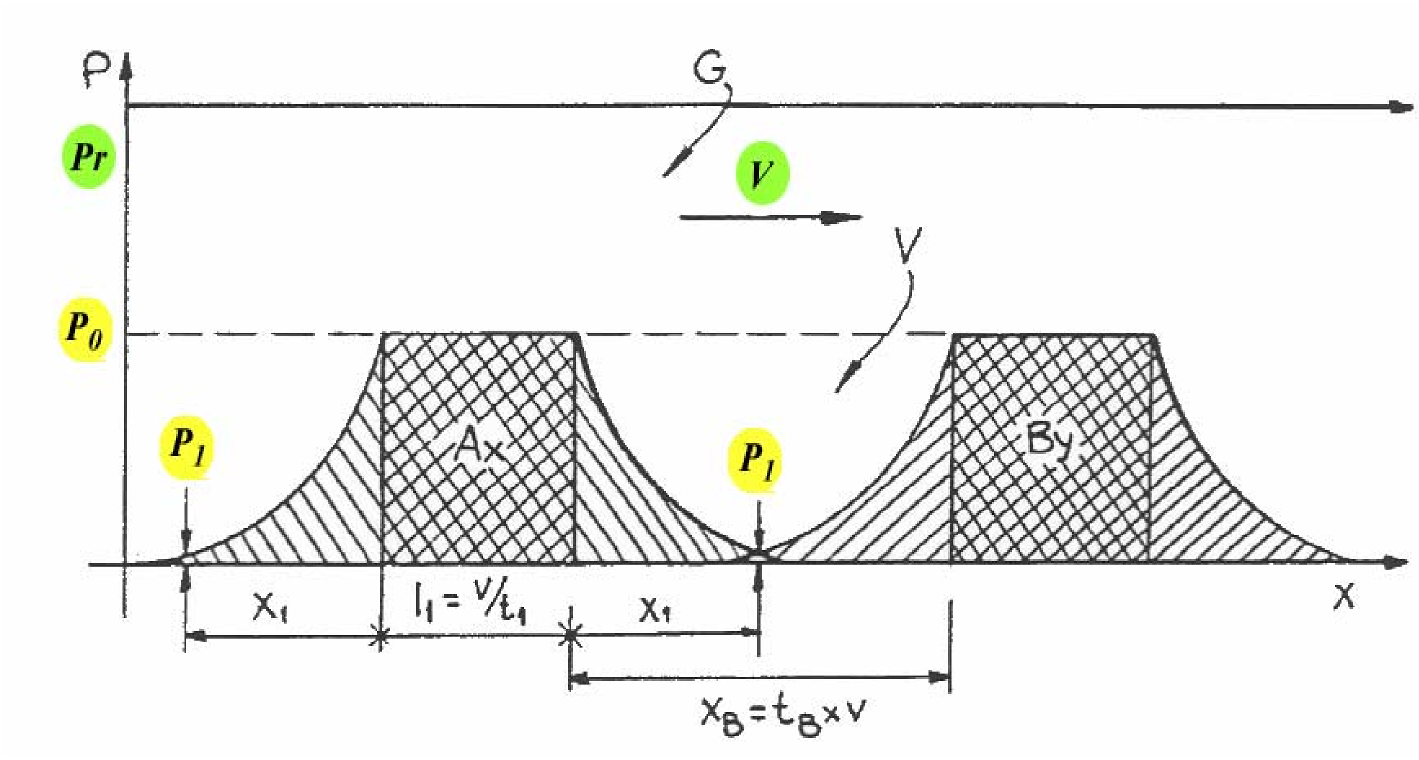
Single Wafer Horizontal Flow

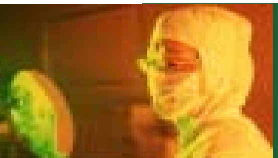
Suntola US #4,389,973 (‘83), Seminal Disclosure



Precursor Diffusion Broadening

Suntola US #4,389,973('83), Seminal Disclosure





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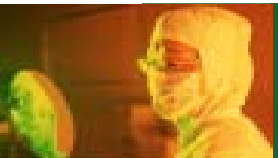
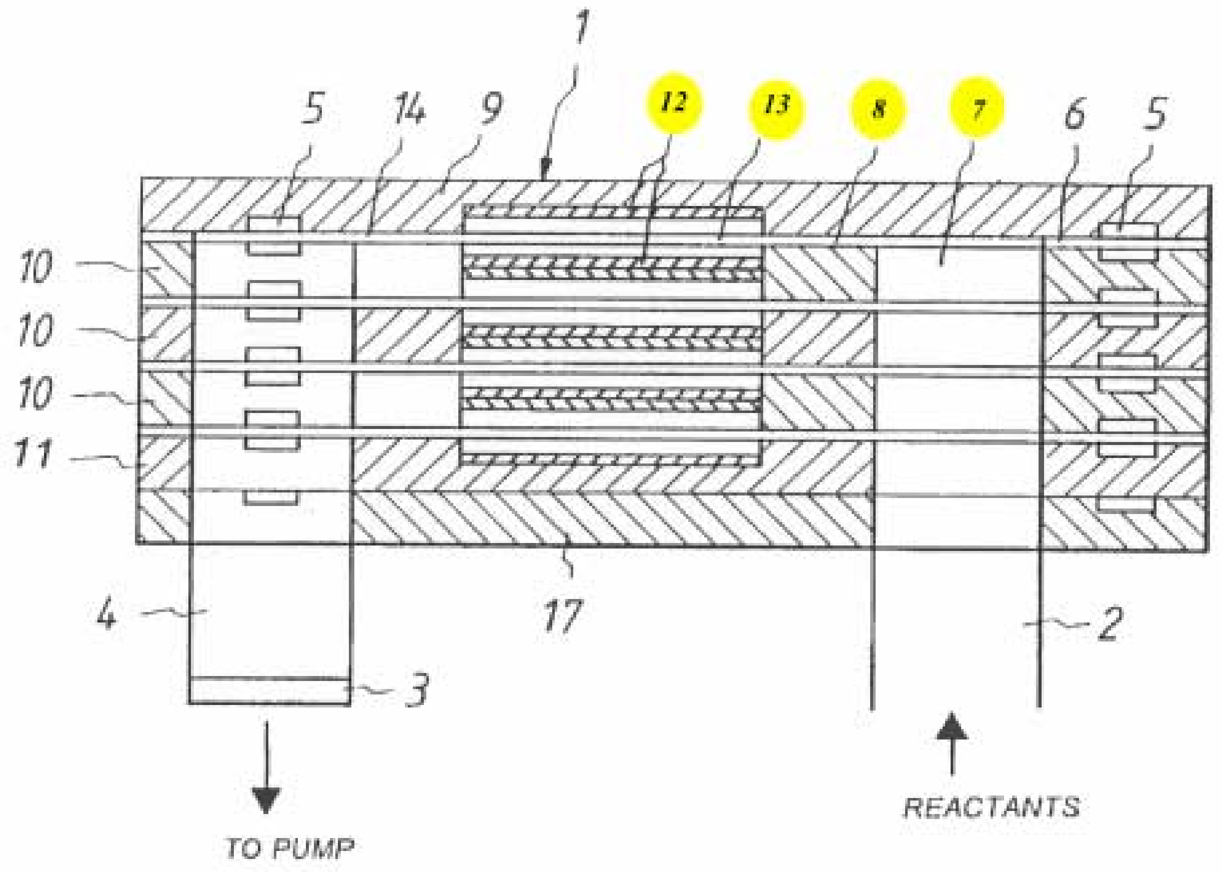
Important Points

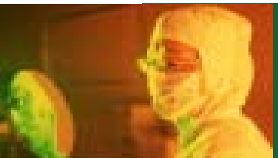
- Diffusion Broadening is a Fundamental Limitation Controlling Pulse Separation
- Classical diffusion model
  – $P(x,t) = P_0 \text{ erfc } (x/2*(Dt)^{1/2})$
- Purge Gas Velocity sets macro flow
  – v = S/A, (S: pumping speed, A: reactor area)



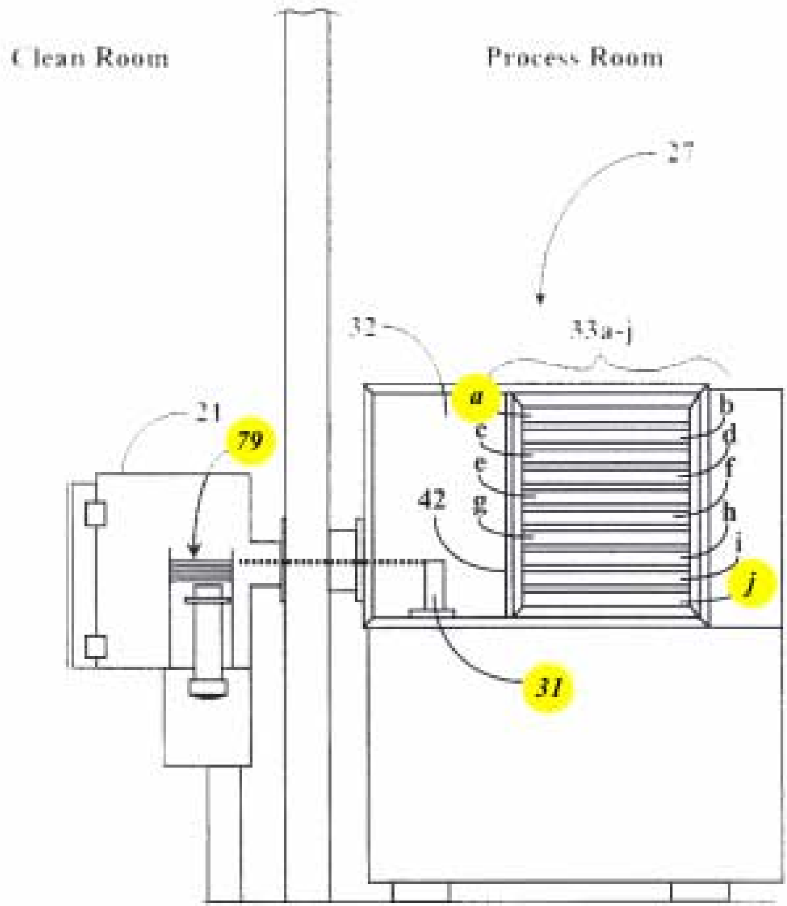
Batch Horizontal Flow

Suntola, US #5,711,811 (‘98)



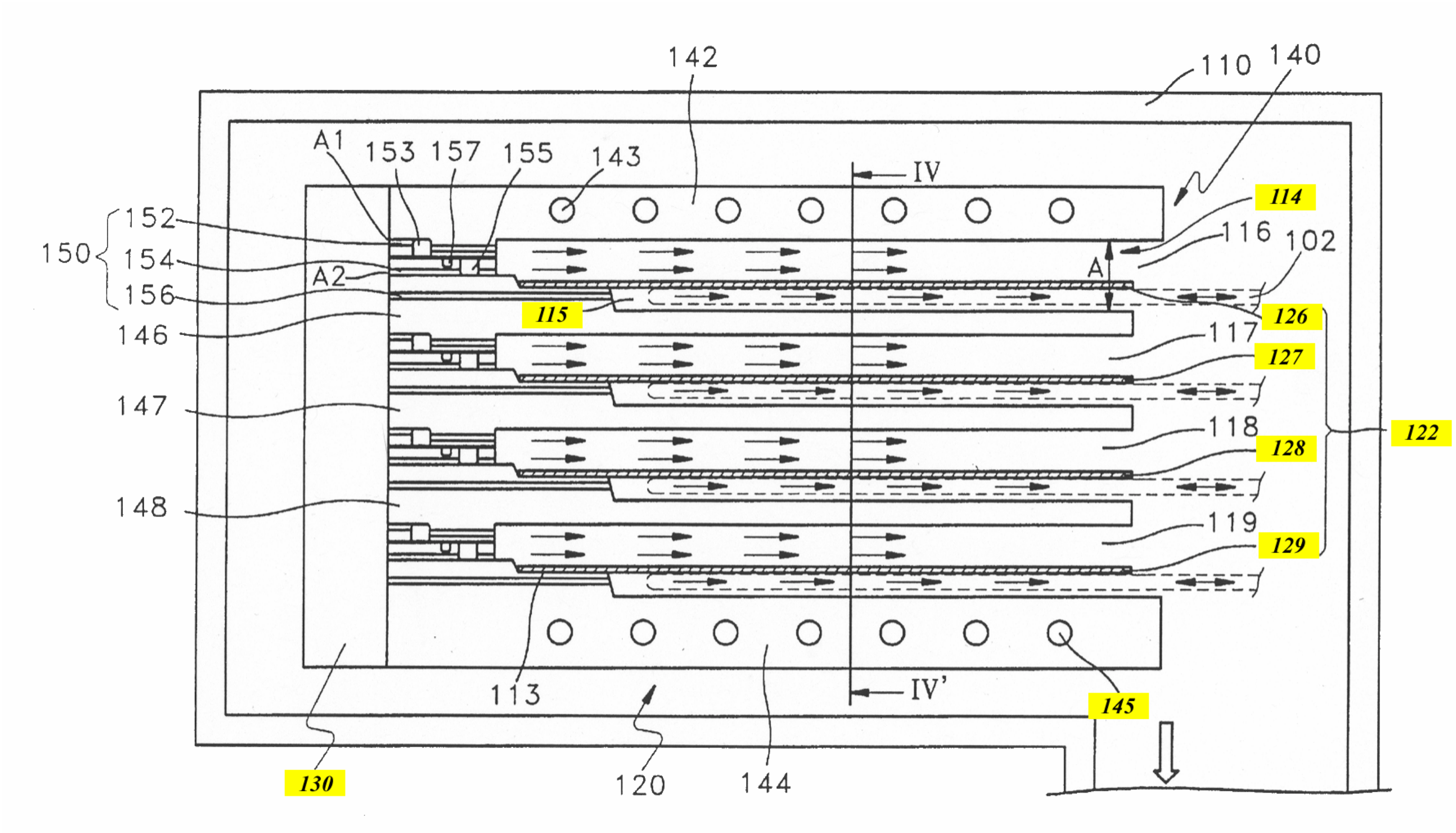


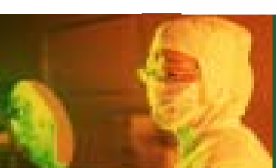
Batch Horizontal Flow with Loading Mechanism
Gadgil, US #5,879,459 ('99)



Batch Horizontal Flow

Hyun, US#6,042,652 (2000)





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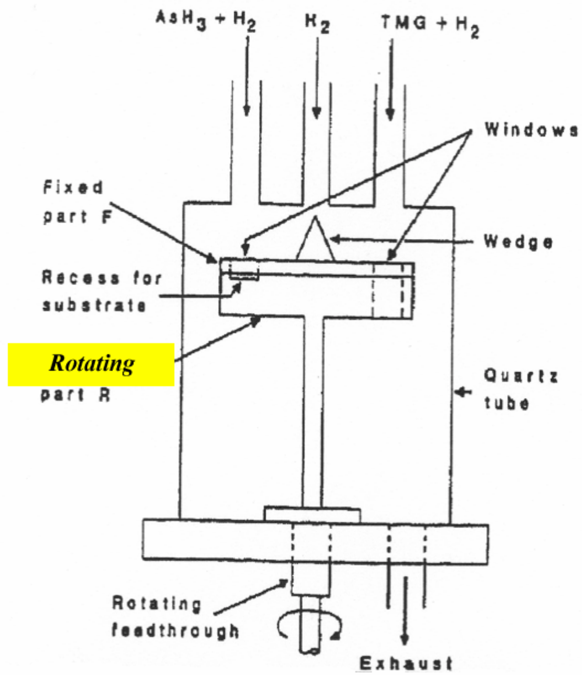
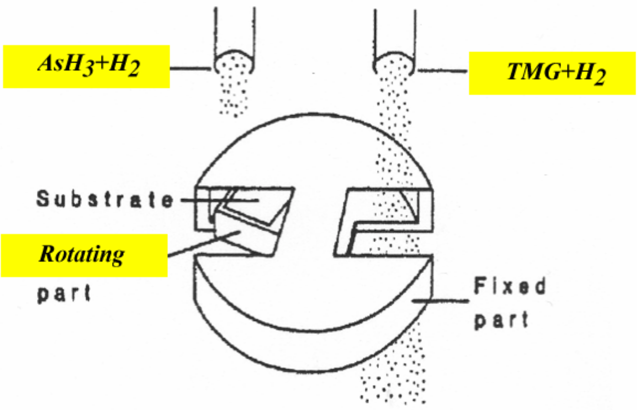
Multi Wafer Vertical Flow

Yoder US# 5,281,274 (‘93); Tischler & Bedair

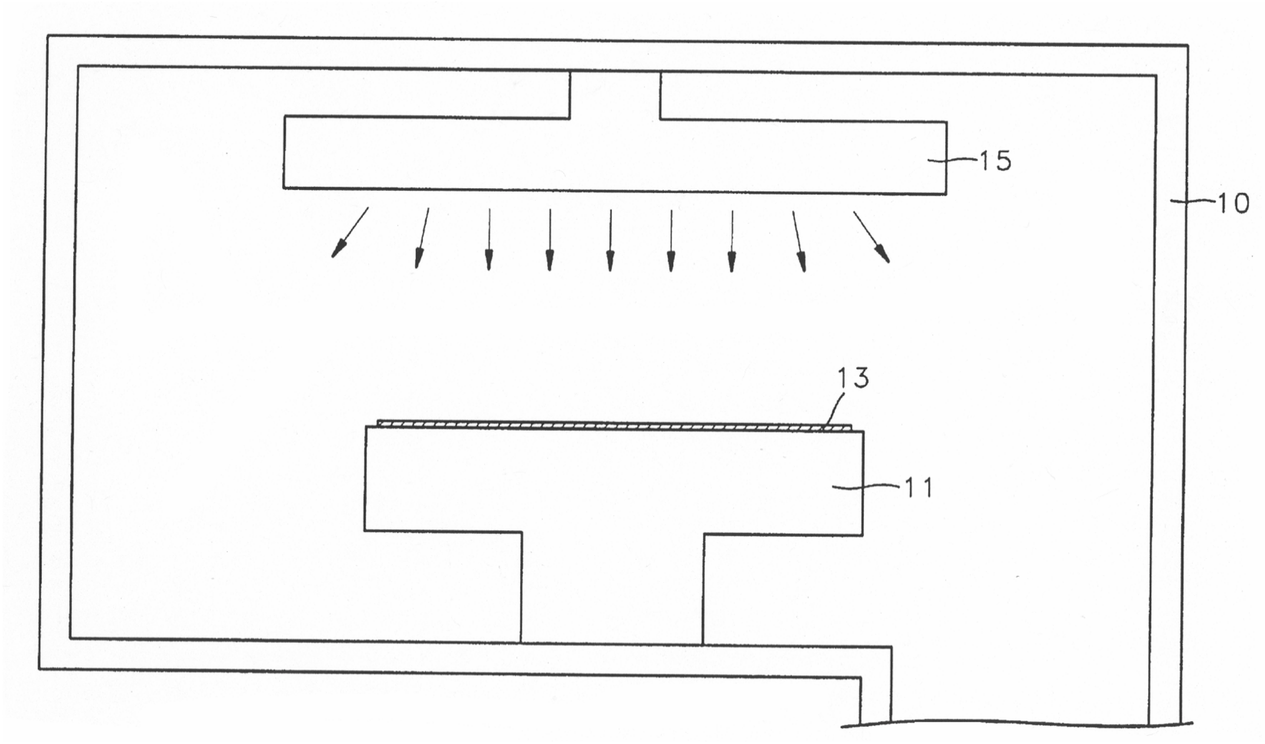
Localized Steady Flow, Rotating Wafers





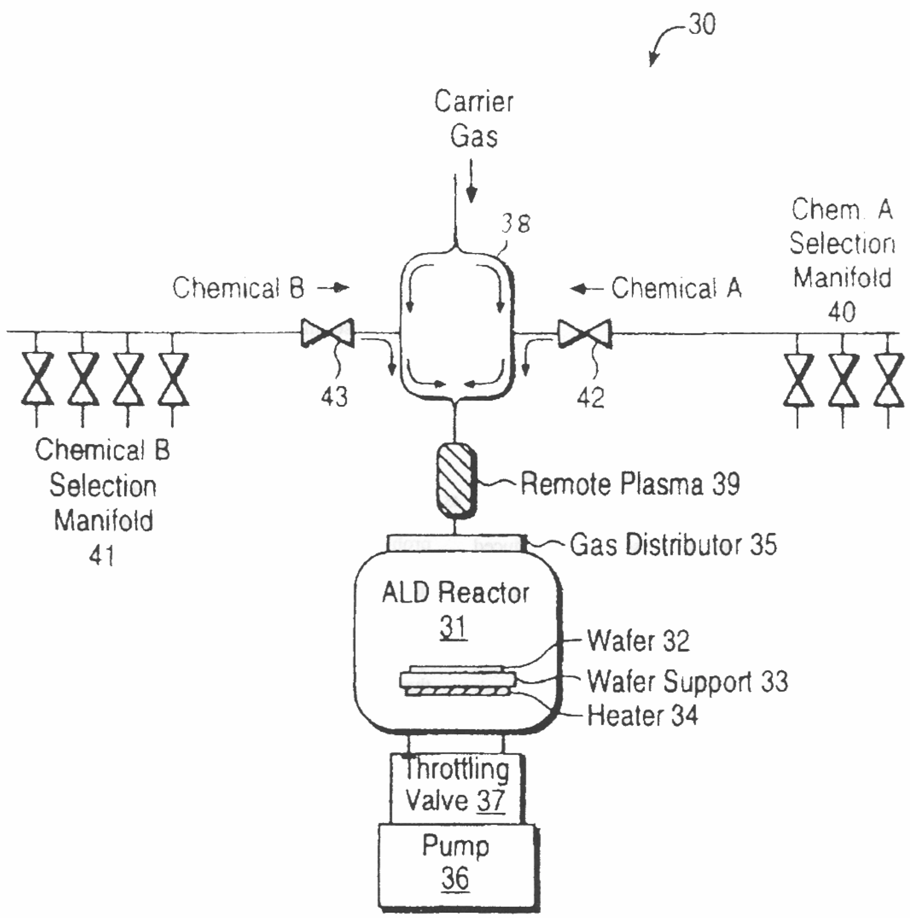
Single Wafer Vertical Flow

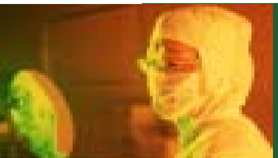
Hyun (2000) Shows as Prior Art



Manifold and Single Wafer Vertical Flow

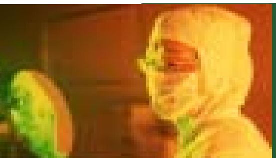
Sneh, US #6,503,330 (2003)





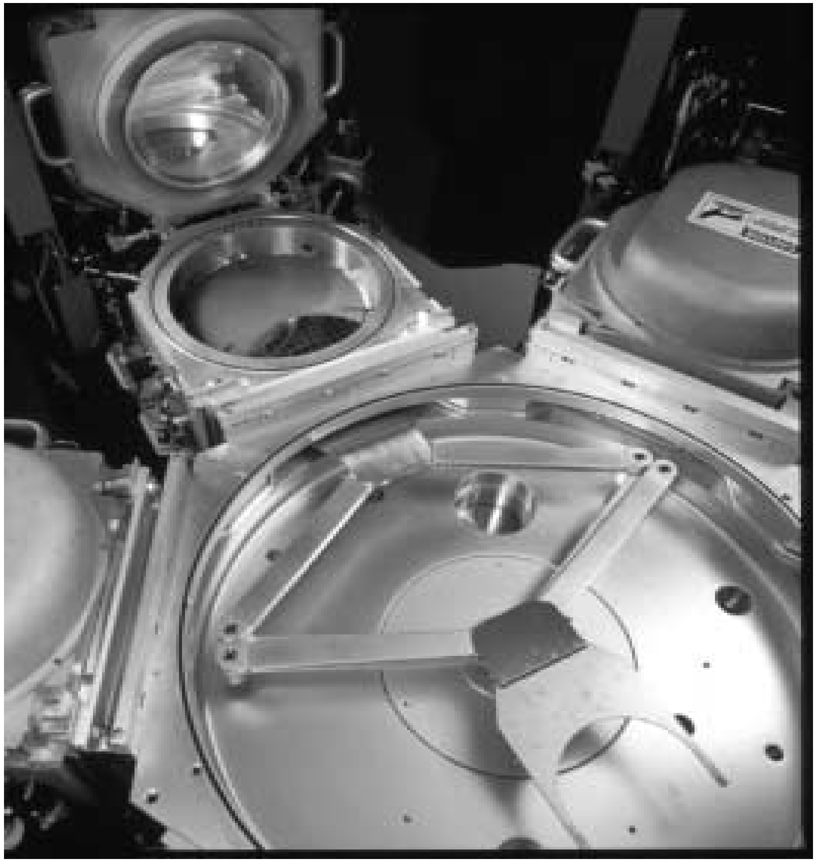
ALD Reactors

- System Approaches
  - Drop ALD into a core CVD 200mm, 300mm system
  - Use an ALD heritage system and add handling
- ALD Processes Scaling for wafer size
  - With the right hardware and operational methods, scaling can be demonstrated quickly



Handler and Chamber Views

- Simplified design with access and ease of maintenance

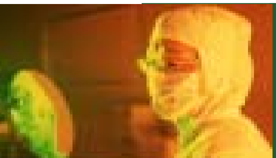


Single Wafer

- SW Process Control
  - Insitu Processes (plasma)
- Std. Vac. Wafer Handling
  - Cluster Tool Flexibility
- Many Film Metrics Estab.
- In Ltd. Production (TFH)
  In Pilot Production (SC)
- TP/Cost ok (ultra thin films)
- - Cost > Thermal Furnaces
- So far, use limited to ultra thin films

Batch

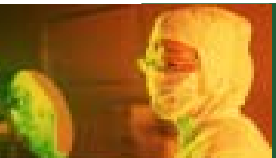
- Higher Throughput
- Lower Cost
- Potential for Thick Films
- In Ltd. Production (FPED)
  Under Evaluation (SC)
- - Backside deposition
- - Horizontal flow →2 r
- ? Process Control



ALD Process Control

A Study of the Variance in Growth Rate with Temperature, Pressure, Pulse, and Purge Times,

Ref. Londergan, et.al. ECS 2002



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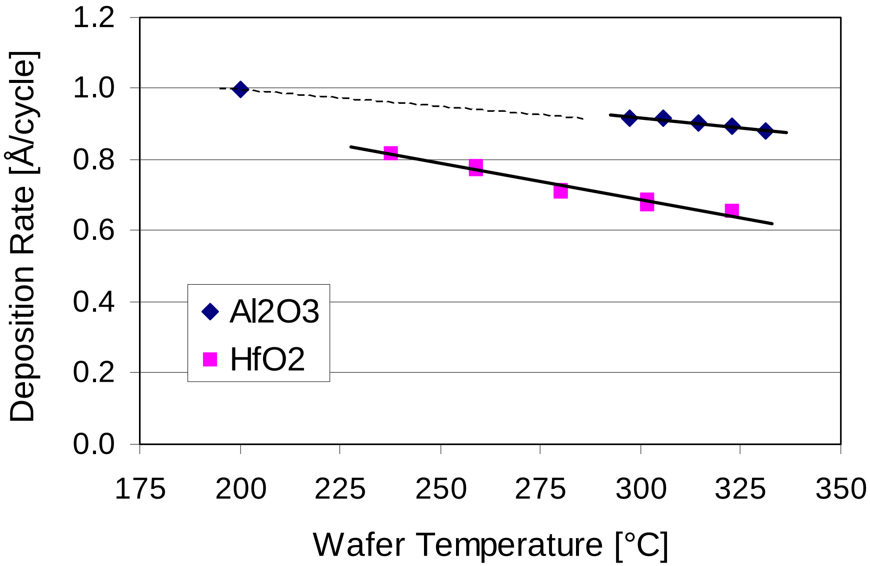
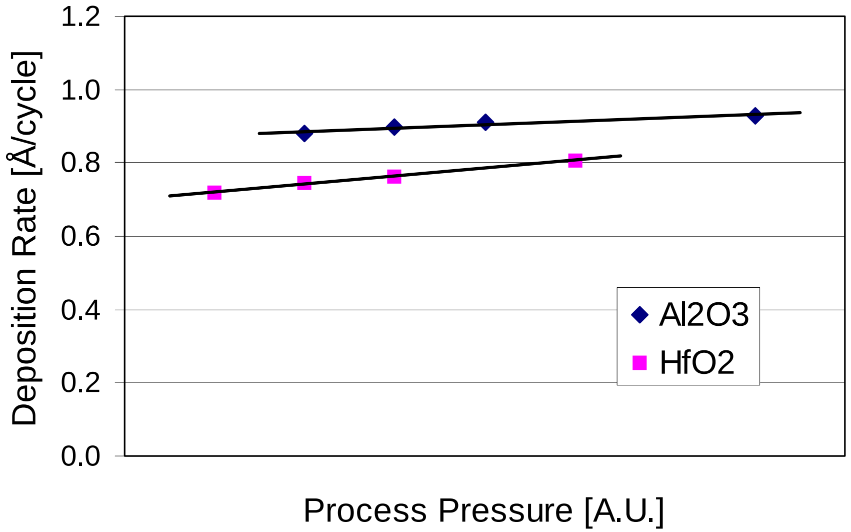
ALD Process Window

Temperature:
hydroxyl coverage

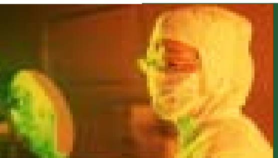


Pressure:
residence time



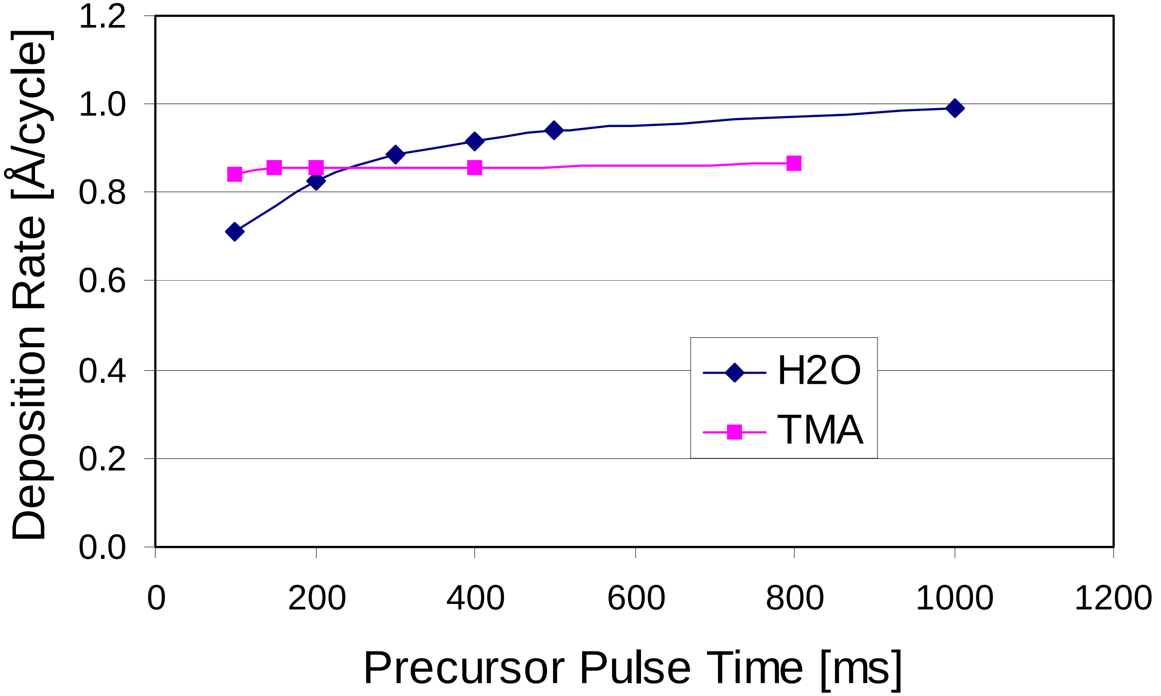
Al_2O_3: ΔGr.Rt./ΔT~ **-1x10^{-3}** Å/cycle ^{o}C ΔGr.Rt./ΔP ~ **2x10^{-4}** Å/cycle mTorr

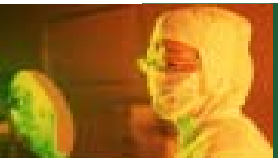
HfO_2: ΔGr.Rt./ΔT~ **-2x10^{-3}** Å/cycle ^{o}C ΔGr.Rt./ΔP ~ **4x10^{-4}** Å/cycle mTorr



Saturation Characteristics of Al_2O_3

- TMA: “Classic” ALD Behavior
- H_2O: Approaches Saturation





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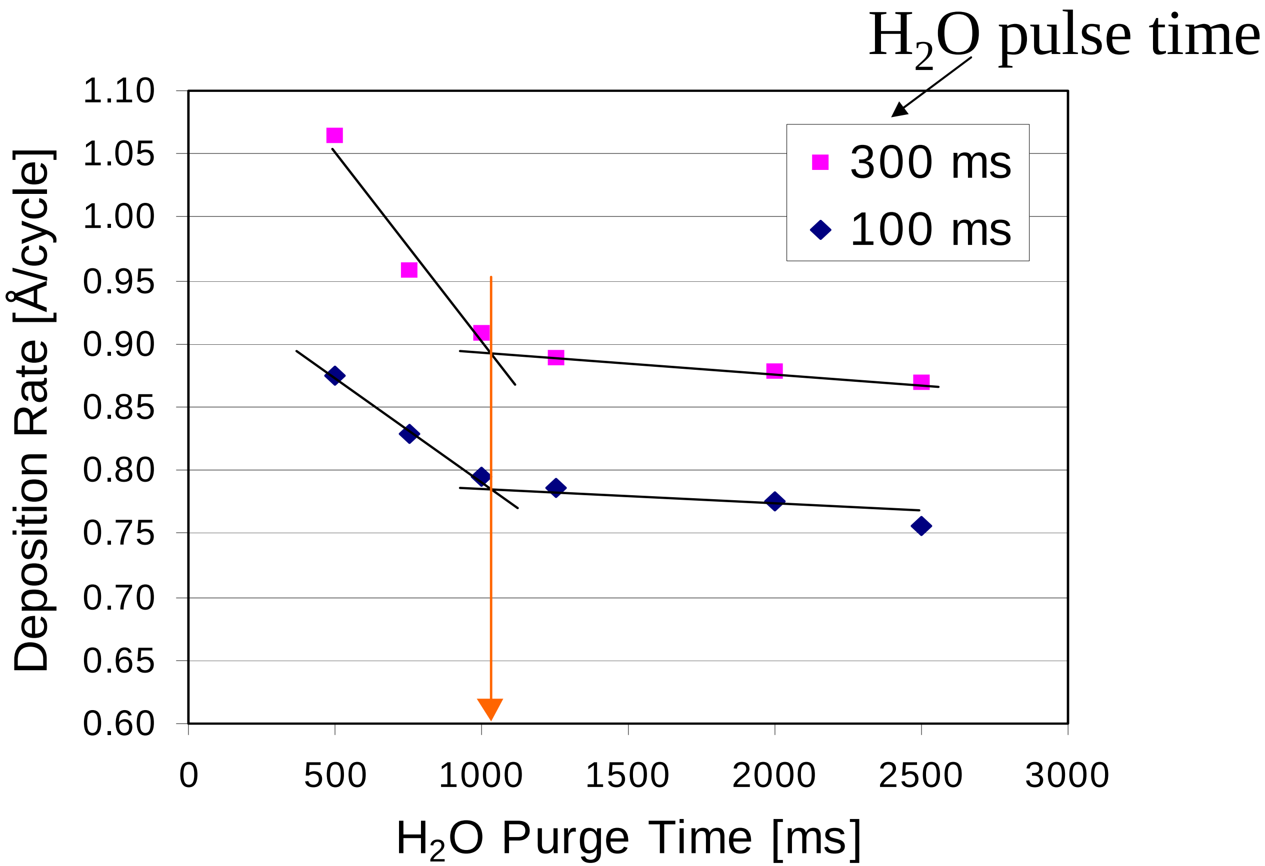
Water Purge Characteristics: Al_2O_3

Can operate at low purge times

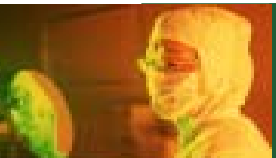
if parasitic CVD added to ALD meet requirements



ALD Process Window

	Al_2O_3	HfO_2
Δ Gr.Rt. / Δ Deposition Temperature [Å / cycle ºC]	-1×10^{-3}	-2×10^{-3}
Δ Gr.Rt. / Δ Process Pressure [Å / cycle mTorr]	2×10^{-4}	4×10^{-4}
Δ Gr.Rt. / Δ Metal Precursor Pulse Time [Å / cycle ms]	$< 10^{-6}$	$< 3 \times 10^{-5}$
Δ Gr.Rt. / Δ Metal Precursor Purge Time [Å / cycle ms]	-5×10^{-6}	-1×10^{-5}
Δ Gr.Rt. / Δ Water Pulse Time [Å / cycle ms]	2×10^{-4}	4×10^{-4}
Δ Gr.Rt. / Δ Water Purge Time [Å / cycle ms]	-1×10^{-5}	-1×10^{-5}

Excellent control of Al_2O_3 and HfO_2



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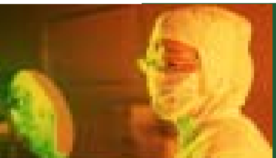
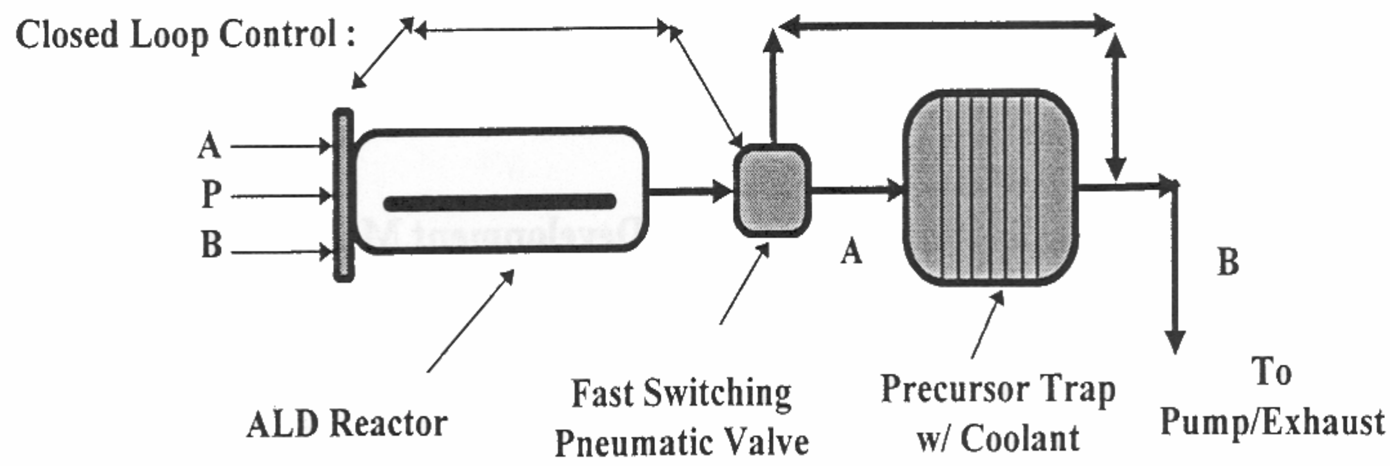
ESH Implications

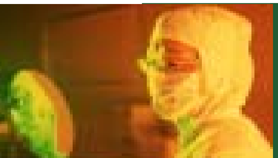
- Waste management
  - Consider the separation and entrapment of precursors and by-products in the exhaust zone
  - Opportunity to reclaim of precious elements
- Reactor design with reclaim functionality
  - For minimal precursor use
  - To limit downstream precursor mixing



Schema of Down-stream Precursor Entrapment Process

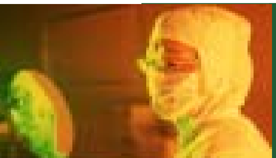


Schematic of the Down-stream Precursor Separation Process.
A, B : Reactive Precursors, P : Purge, A : Precursor for Separation & Recycling.



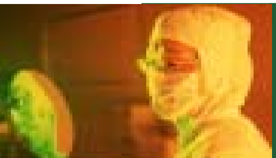
Generic Example Approach

- Closed-loop arrangement with fast gas switching valves in inlet manifold and a fast switching valve with a predetermined delay down stream
- Unused precursor may be collected in a trap
  - Coolant or adsorption (passive mode)
  - Heterogeneous reaction, e.g reactively plate out material (active mode)



Concluding Remarks

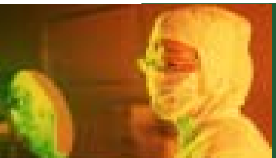
- Many reactor varieties exist
  - Pros and cons under evaluation
- Process control excellent and demonstrated
- Scaling ALD from 200 to 300mm demonstrated
- Improved ALD reactor design is possible
- Precursor recovery a potential opportunity



ISO 14001
Environmental Management System
<u>The Benefits</u>

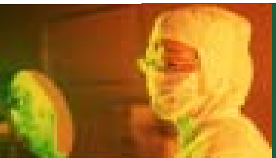
- **Environmental Objectives part of Formal Management Reviews.**
- **Increased Employee Awareness about the Impact they have on the Environment at Work and at Home.**
- **Normalized Objectives for Reduction, Recycling, Reuse and Substitutions**
- **Compliance with Local, State and Government Laws and Regulations**

- **Distinguishes Companies who are Concerned about the Environment Worldwide**
  - **<u>Genus: An ISO 14,000 Certified Company</u>**



ISO 14001
Environmental Management System
Accomplishments at Genus

- **The Product Development Process Incorporates Environmental Awareness. Product Substitutions, Reuse and Recycling are Evaluations and design Criteria.**
- **Reduced Non-Hazardous Waste Disposal by 25%.**
- **Reduced Electricity Use by 25%.**
- **Completed a Less Toxic Chemical Substitution without Process Degradation.**



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