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Towards a roll-to-roll ALD process

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ASTRaL

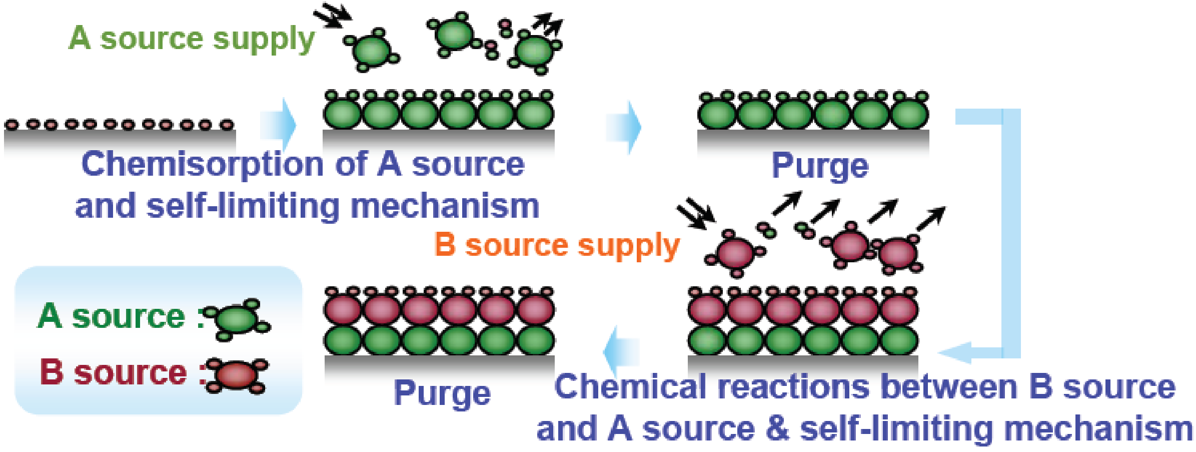
Outline

- Basics of atomic layer deposition (ALD)
- General configuration of batch process
- Configurations for a roll-to-roll process
- Continuous ALD process
- Process characteristics
- Next steps
- Conclusions

Basics of ALD process

- Chemical vapour deposition process.
- Typically uses two precursors to form film material.
  - for example aluminium oxide (most studied material)
  - uses trimethyl aluminium (TMA) and water as the precursors
- Precursors must have high enough vapour pressure
  - can be liquid, solid or gas
  - liquid: TMA, $TiCl_4$, water
  - solid: $HfCl_4$, Cu hexafluoroacetylacetonate
  - gas: ozone, hydrogen sulphide
- These precursors normally react spontaneously when they come in contact
  - form a powder in the gas phase, no use for film deposition
  - want a *surface* reaction so that oxide is only formed on the substrate
- Solution: Only allow precursor to reach the substrate one at a time
  - no reaction in the gas phase
  - reaction only occurs between molecules which have been bonded to the surface

Process cycle repeated as many times as required



A source supply

Chemisorption of A source and self-limiting mechanism

Purge

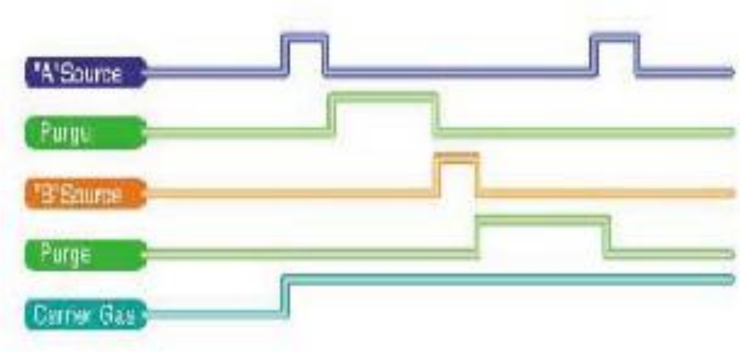
B source supply

Chemical reactions between B source and A source & self-limiting mechanism

Purge

A source :

B source :



Characteristics of ALD

- Film growth can be completely conformal, even on complex shapes, in pores and holes.

- Film uniformity is excellent.

- Surface area for coating can be large.
  - many square metres

- Film thickness is proportional to the number of deposition cycles.

- Deposition speed is suitable for production processes

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- Film thickness is proportional to the number of deposition cycles.
- Deposition speed is suitable for production processes
- ***Needs a batch process***
- For very large scale production, a roll-to-roll system is needed
  - web treatments
  - packaging, plastic electronics, etc.

Needs a change of philosophy

- Batch system uses a ***stationary*** substrate and ***time sequenced precursor and gas pulses*** to obtain the sequential exposure of the substrate to different materials.

However

- Same effect can be achieved using ***constant*** gas flow zones ***separated in space*** and a ***moving*** substrate in order to obtain the time sequential exposure.

Several advantages

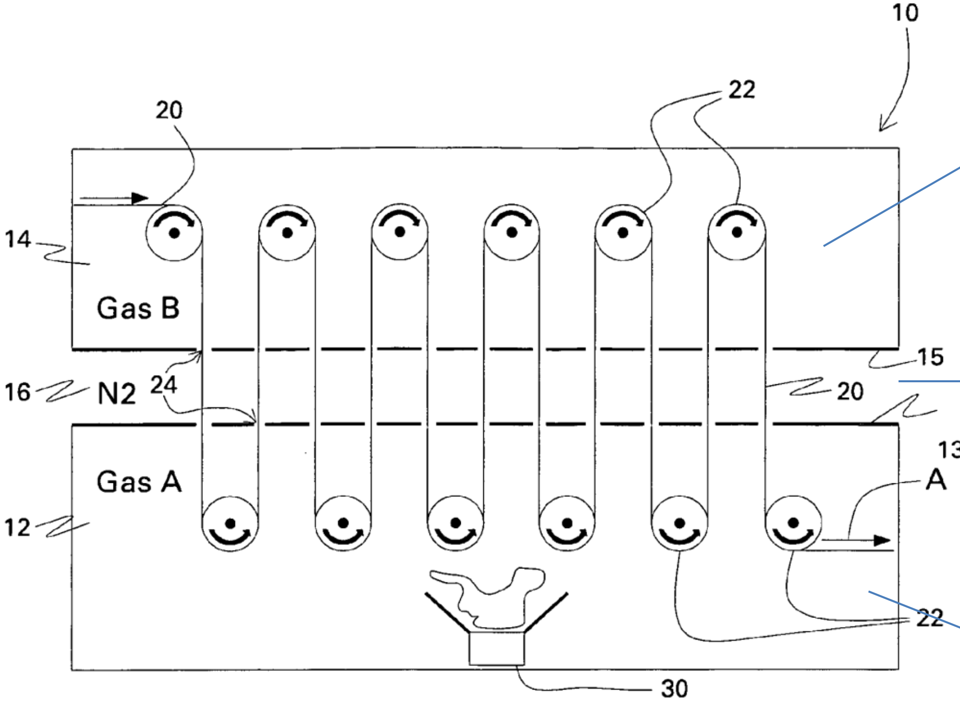
- Moving substrate allows a continuous coating process which lends itself to roll-to-roll coating.
- Constant gas flows means no time switching of gases.
- Cycle time depends on speed of movement of substrate between the gas flow zones.

How to achieve this?

- A number of schemes have been proposed for achieving continuous coating based on this principle.
- Critical factor is to ensure no intermixing of precursor gases.

Possible roll-to-roll systems

US2007281089A1 General Electric 2007

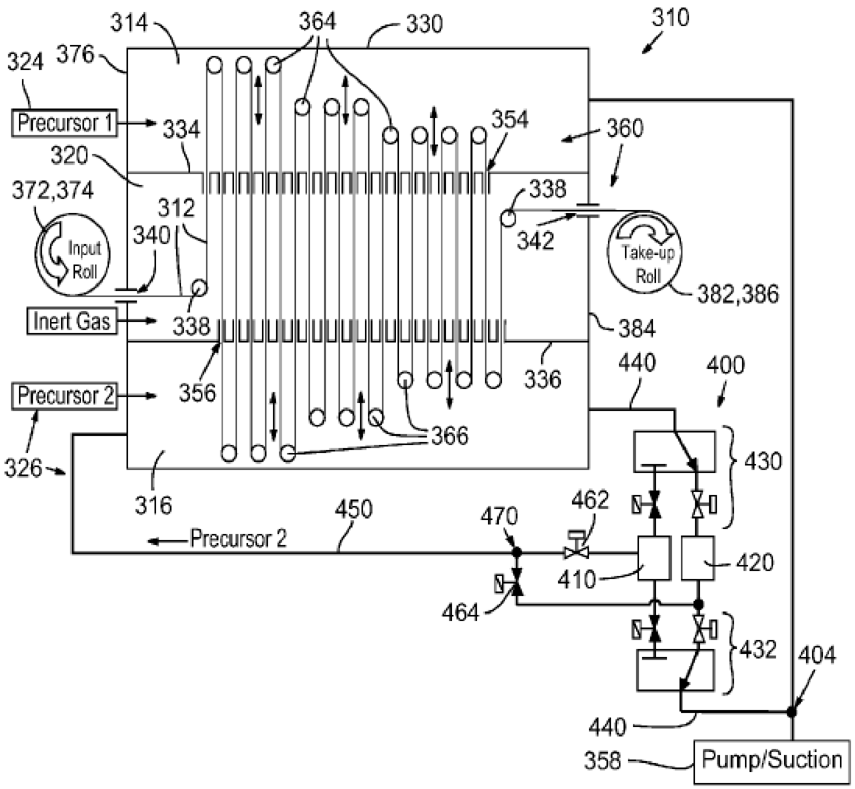


precursor
zone 1

purge
zone

precursor
zone 2

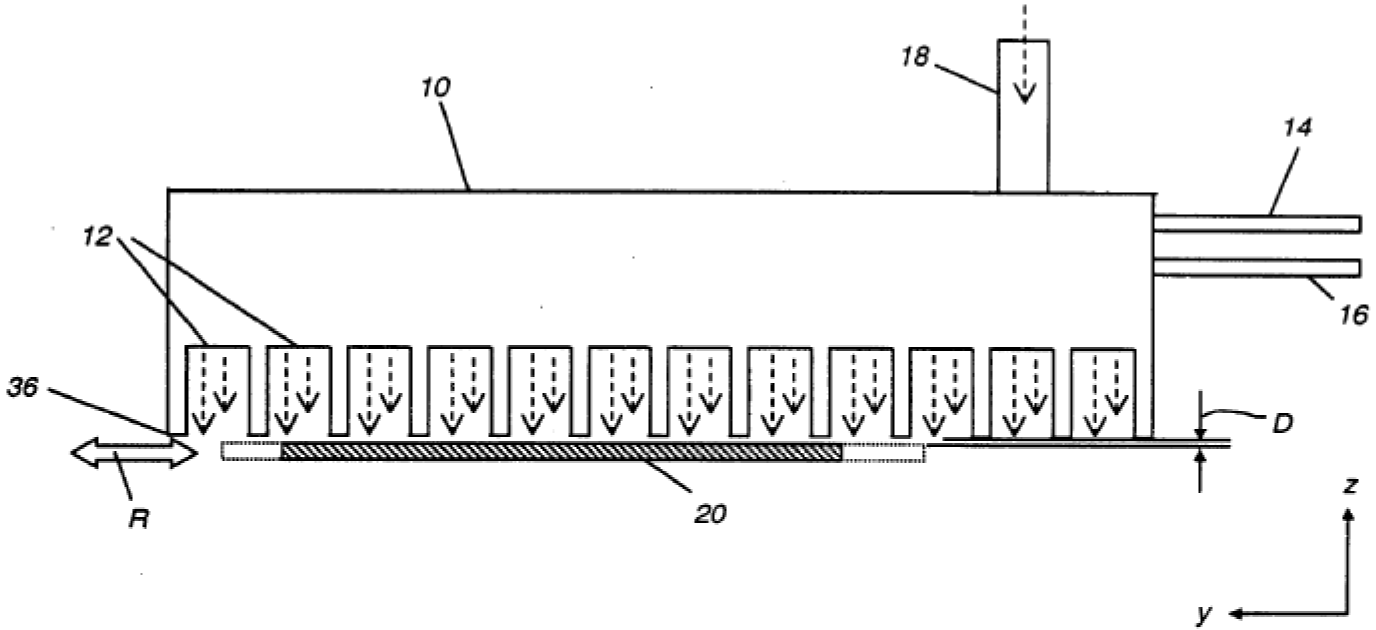
US2007224348A1 Planar 2007



Possible issues:

- Cracking and abrasion of web as it passes over rollers
- Both sides are coated
- Good gas separation may be difficult
- Easy to incorporate multiple cycles of deposition
- Has been demonstrated by Lotus (Planar spin-off) in USA
- Web speeds of several 100s m/min

US2007238311A1 Kodak 2007



Separation between substrate and coating head is set by levitation of the head due to the gas pressure

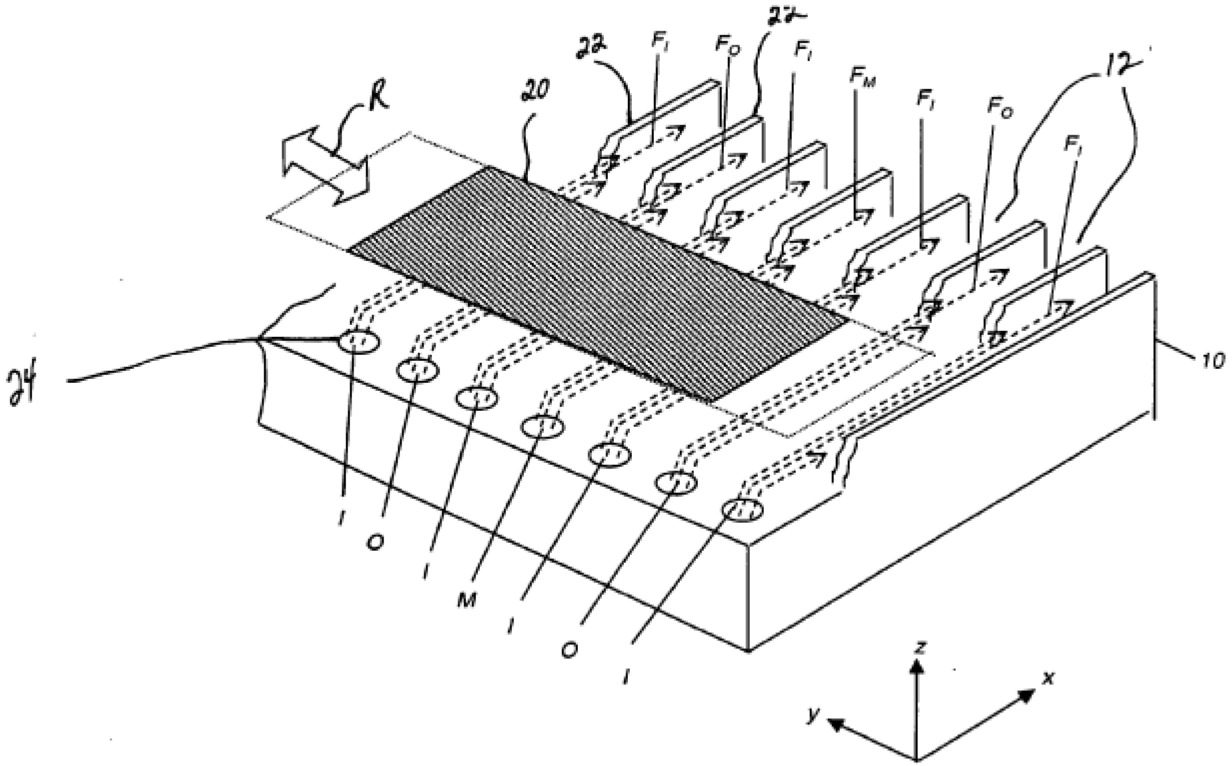
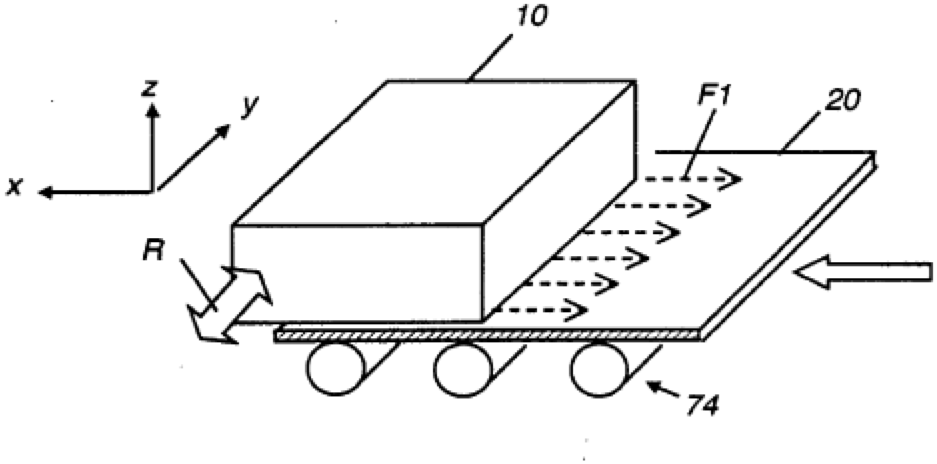
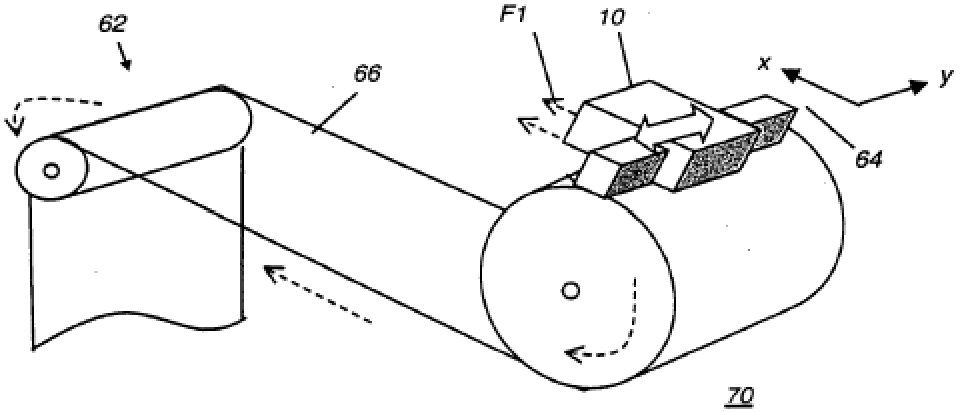


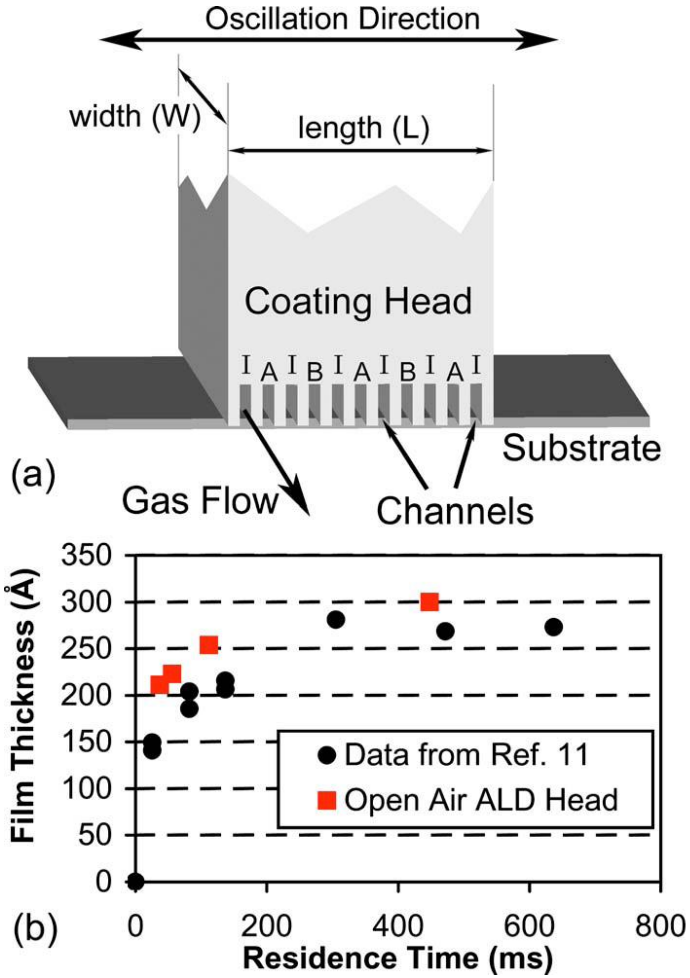
FIG. 6



- Coating head is scanned over rigid substrate
- Each pass gives multiple cycles depending on construction of coating head
- Can be used at atmospheric pressure



- Could be perhaps extended to a web coating system.



Stable ZnO thin film transistors by fast open air atomic layer deposition

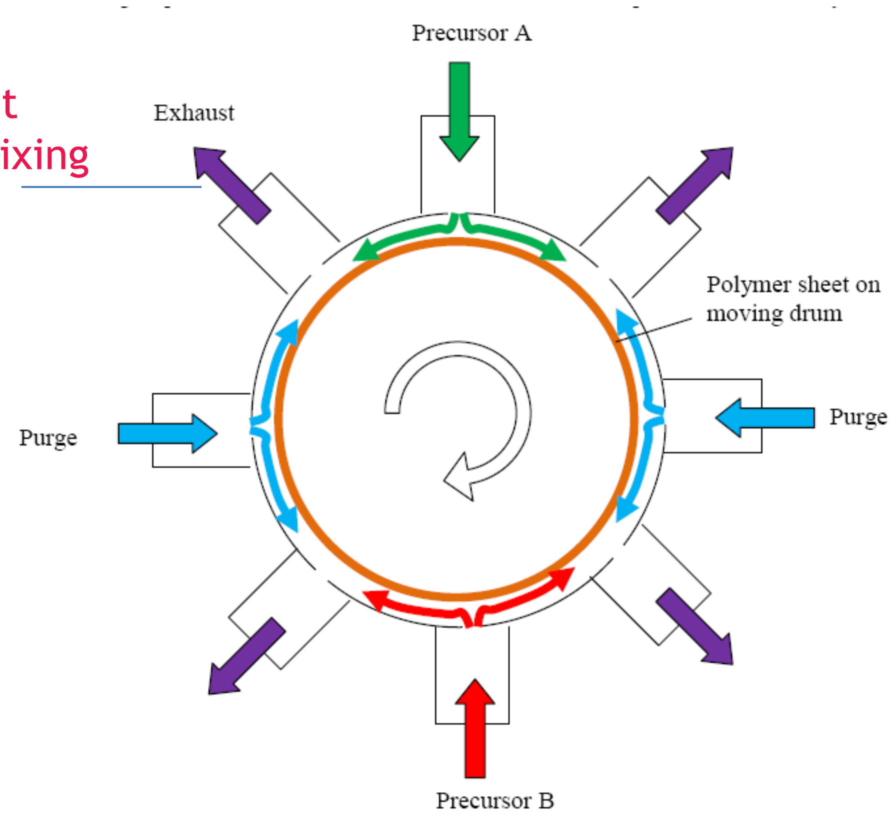
Applied Physics Letters **92, 192101 2008**

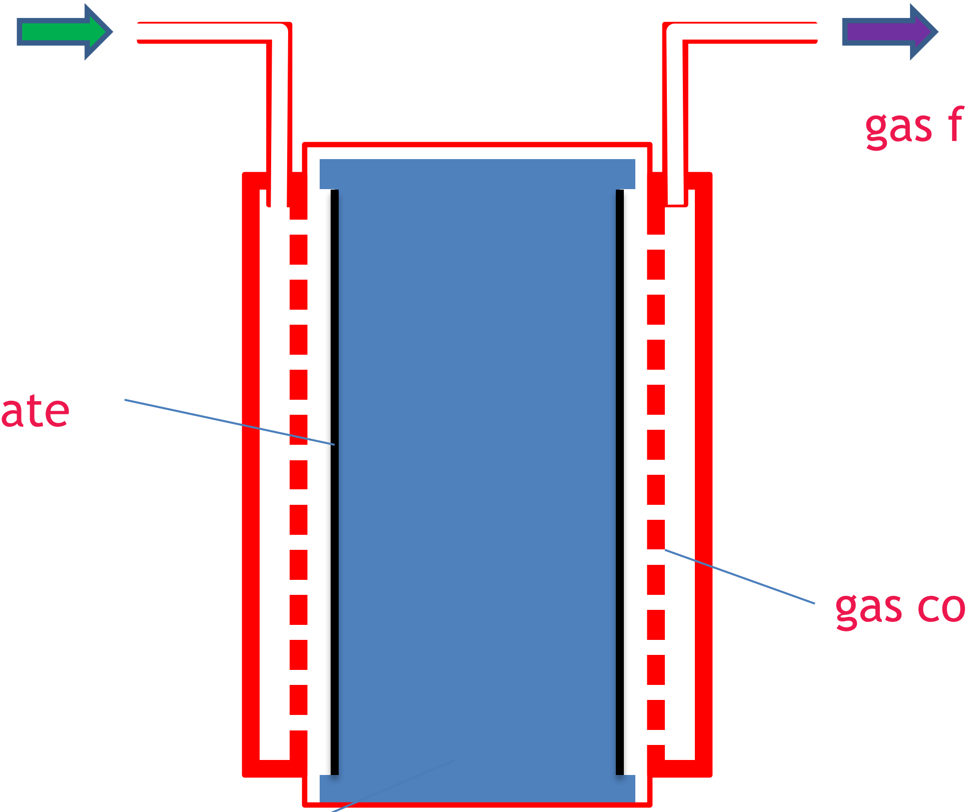
ASTRaL approach

- TEKES project: Continuous Atomic Layer Deposition Process (CALD)
- Aim: to develop the technology for roll-to-roll coating for diffusion barrier layers.
- Build an experimental system which would show the feasibility of roll-to-roll coating
- Based on the movement of a flexible substrate through precursor and purge gas zones.

System configuration

Vacuum exhaust prevent intermixing of precursors





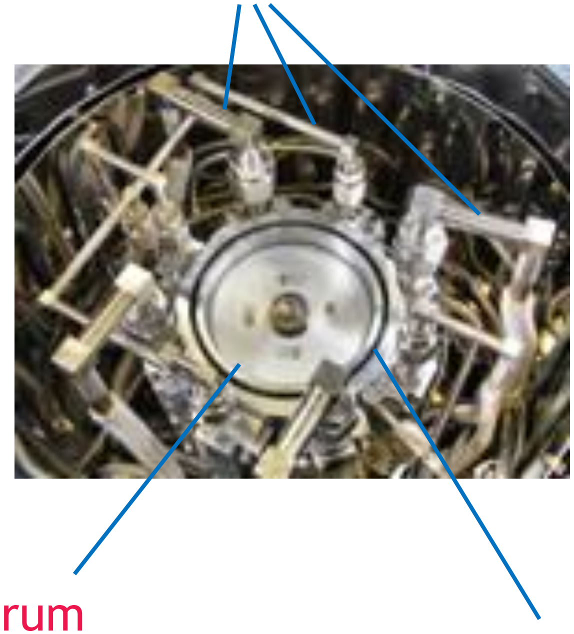
gas flow in or out

flexible substrate

gas control nozzles

rotating drum

precursor inlets and exhausts



drum

deposition chamber

courtesy Beneq Oy

System parameters

- Substrate maximum size: 310 mm x 120 mm
- Rotational speed: up to 1000 rpm
- Chamber temperature: room temperature to 200 C
- Current process: aluminium oxide from TMA + water
- Planned future work: titanium oxide
- Carrying out basic deposition studies
  - ALD deposition parameters
  - uniformity
  - speed
  - precursor efficiency

Preliminary results

- ALD growth achieved for Al_2O_3 from TMA and H_2O
- Deposition temperature 100 C
- Substrates PET sheet metallised with Ti (for ease of measurement)
- Deposition rate shows a region independent of precursor dose
  - deposition rate ~1.2 Å/revolution
  - conventional ALD at the same temperature with the same precursors gives ~1 Å/cycle
- Deposition rate is independent of rotation speed within certain ranges depending on precursor flow rate and other gas flow parameters.
- Uniformity is good over the whole substrate
- High precursor efficiency: estimated to be >80%

Next steps

- Continue to explore gas flow parameter space
- Measure diffusion barrier performance
- Deposit titanium oxide (should be an easier process than aluminium oxide)
- Set out design principles for roll-to-roll system
  - current system gives one layer per revolution
  - needs to be increased for practical roll-to-roll system

WATCH THIS SPACE!