SPARKNANO

formerly known as SALDtech

Design challenges and solutions for Spatial ALD equipment

Jeroen Smeltink
Systems Architect

Spatial ALD day Tu/e 2022

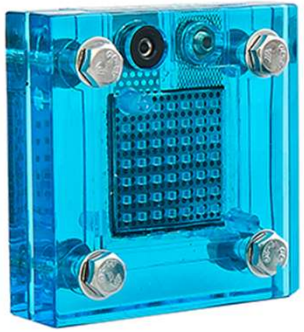
Since June 1st 2022:

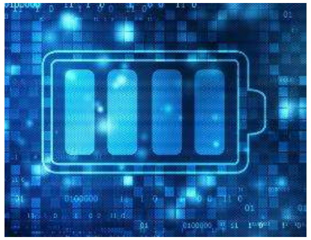
New markets, new products, new customers → New name

SALDtech ⇨ SPARKNANO

www.spark-nano.com

SparkNano introduction



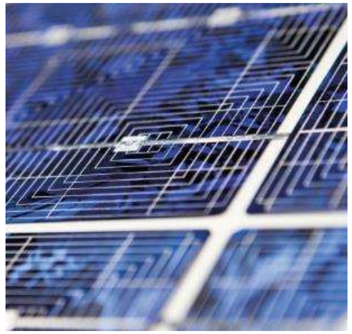


SparkNano (founded in 2018) is a spin-off company of TNO, located in Eindhoven, the Netherlands

We develop and sell large-area **Spatial Atomic Layer Deposition** technology

Our technology enables our customers to apply better, cheaper and higher performing materials for the **electrolysis**, **fuel cell, battery, display** and **solar** markets

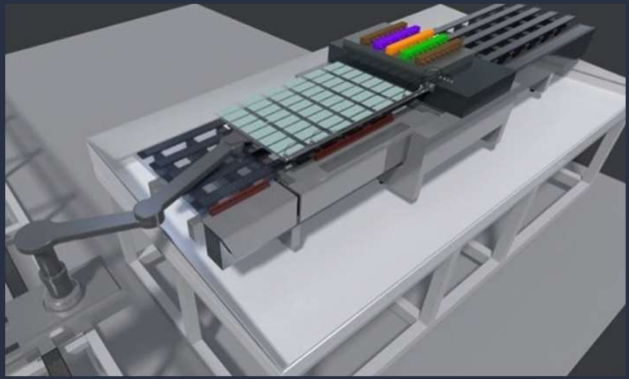
We provide state of the art **lab- and fab-equipment** combined with extensive process and application support

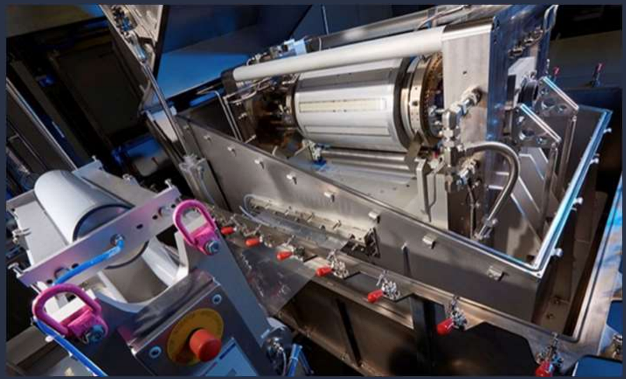


Our products

Spatial-ALD from lab-to-fab

From versatile LAB tools to highly efficient
mass production FAB tools.





LabLine series

versatile and flexible tool for process development and pilot production

Vellum series

mass production tool for flat, sheet-to-sheet applications

Omega series

mass production tool for flexible substrates – roll-to-roll applications

SPARKNANO

A mechanical engineer's perspective...

- Today, we will see many examples of what processes, materials and application can be done by Spatial ALD
- But: to do Spatial ALD, you need to have a working Spatial ALD reactor
- There are quite some mechanical engineering challenges that need to be tackled to design and build a Spatial ALD reactor
  - Moving substrates/injectors with high precision at elevated temperatures
  - Distributing gasses and precursors with high uniformity
  - Handling various kinds and sizes of substrates
  - All under clean, inert and safe operating conditions

- **Today, we will show you Spatial ALD from a different perspective: that of the mechanical engineer**

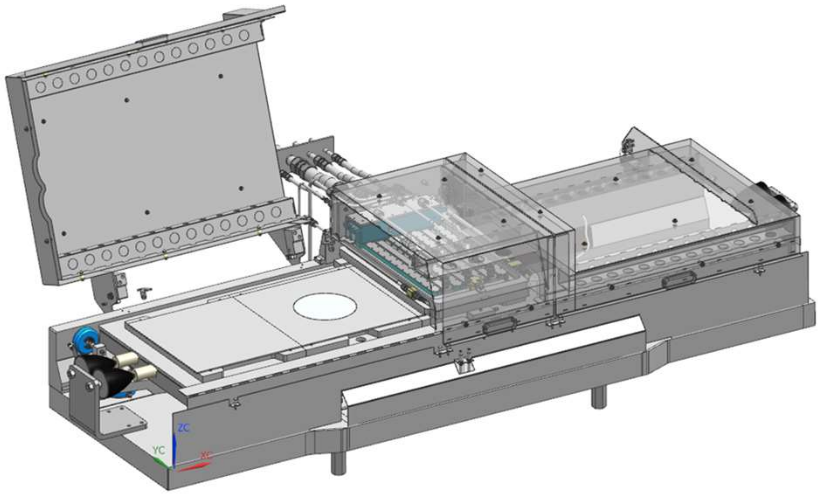
Engineering a Spatial ALD reactor

- A lot of design aspects have to be taken into account during the development of a spatial ALD system

- To meet process requirements such as process temperature, gas flow uniformity, contamination, deposition speed and many more the engineer must be aware of interactions between multiple physical domains and find a well balanced solution.

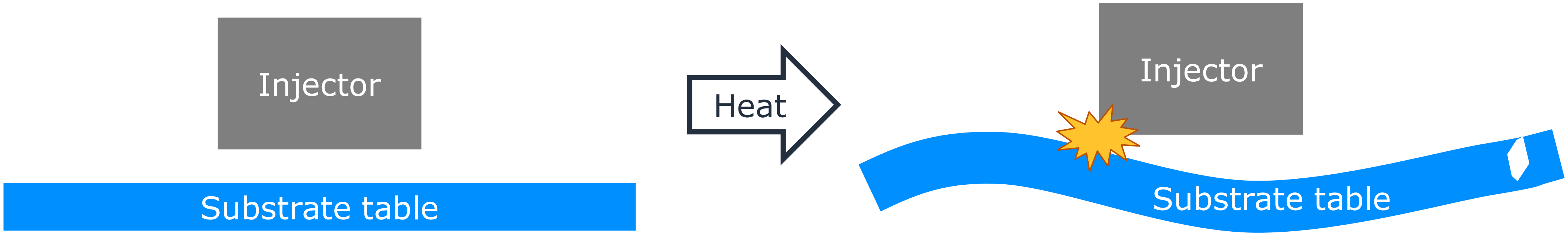
- To give you an impression, we will show two examples of design challenges and their solutions:

  1. **Thermo-mechanical aspects**
  2. **Ensuring uniform gas flows**



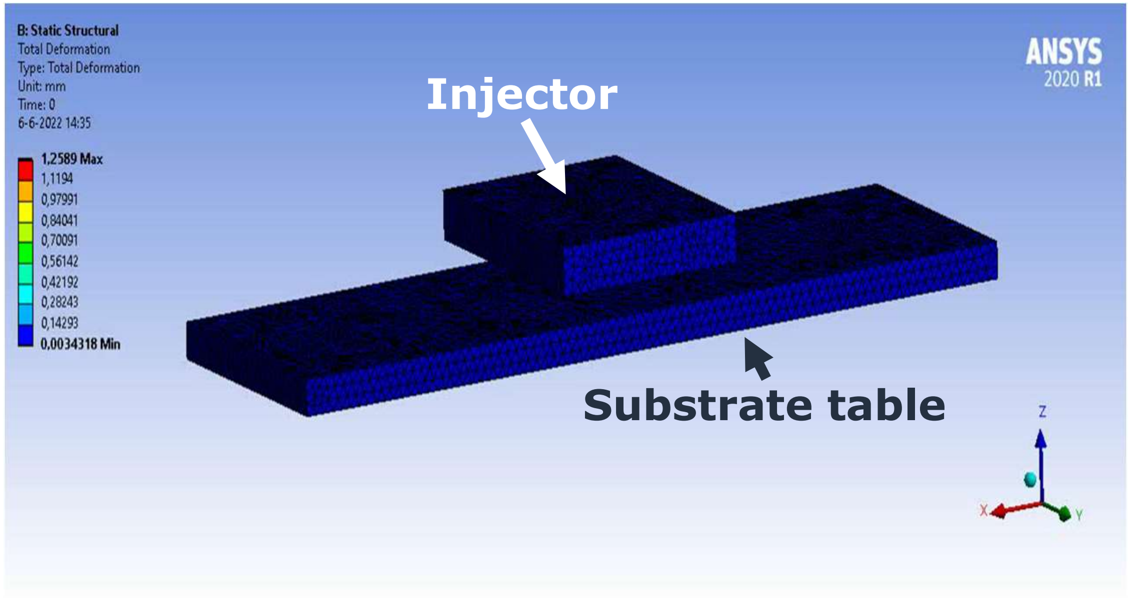
Thermo-mechanical deformations

- Spatial ALD is often performed at elevated temperatures
- Due to thermal expansion, components like injectors and substrate tables expand upon heating
- If this leads to deformations larger than the process gap, we are in trouble…
  - Leads to flow non-uniformities and thickness variations
  - Worst case: a crash…
- Thermo-mechanical modelling is a useful tool prevent problems on forehand



Thermo-mechanical deformations

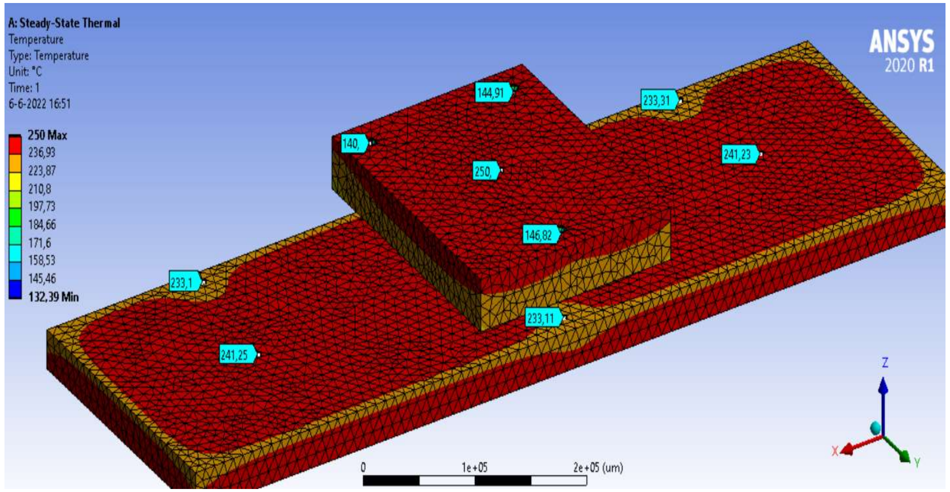
- ANSYS can be used to do thermo-mechanical modelling
- In case of a uniform temperature increase upon heating, all parts will expand uniform and the gap is not affected

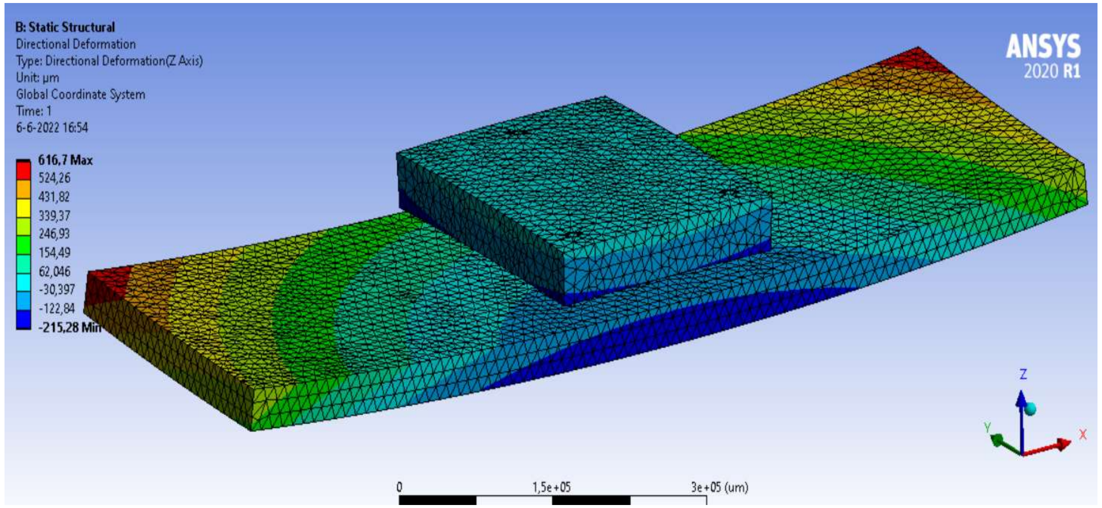


SPARKNANO

Thermo-mechanical behaviour

- In reality, thermal gradients will be present due to heat losses
  - The heat losses are caused by practical limits of insulating the reactor



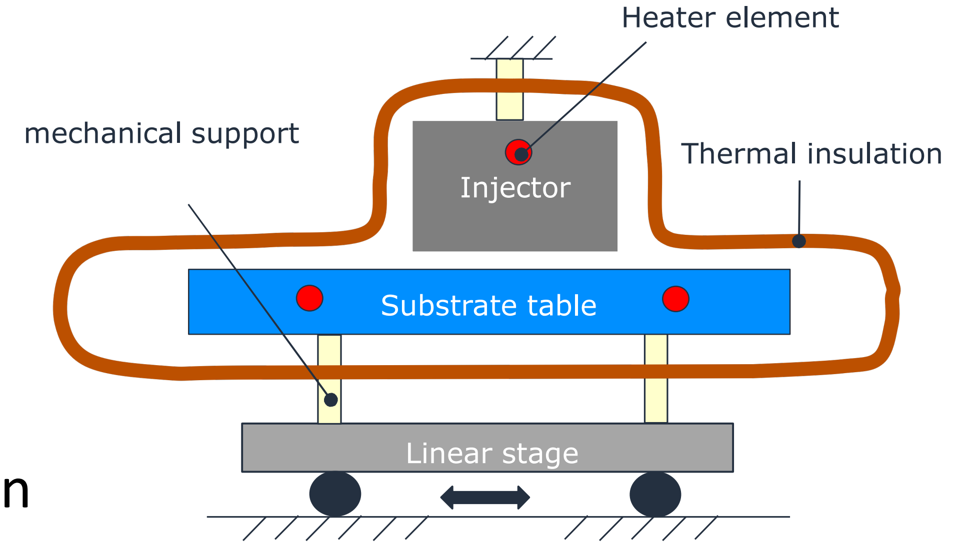


- Thermal gradients will cause internal stresses and deformations
- These deformations can be large enough to cause problems

Thermo-mechanical behaviour

Temperature gradients can be minimized by:

1. Use proper thermal insulation
2. Using materials with a high thermal heat conductivity coefficient (λ) and low thermal expansion coefficient (α)
    - Aluminium, λ= 240 W/mk, α = 24e-6 K^{-1}
    - Stainless steel , λ= 25 W/mk, α = 16e-6 K^{-1})



- However, the choice of material also depend on other factors, like:
    - Max operating temperature
    - Corrosion resistance
    - Manufacturing costs

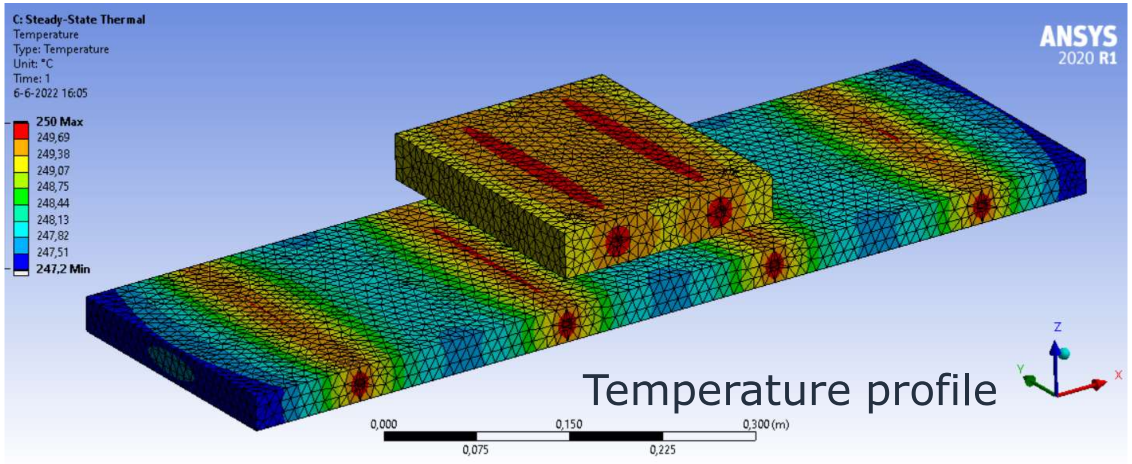
Thermo-mechanical behaviour

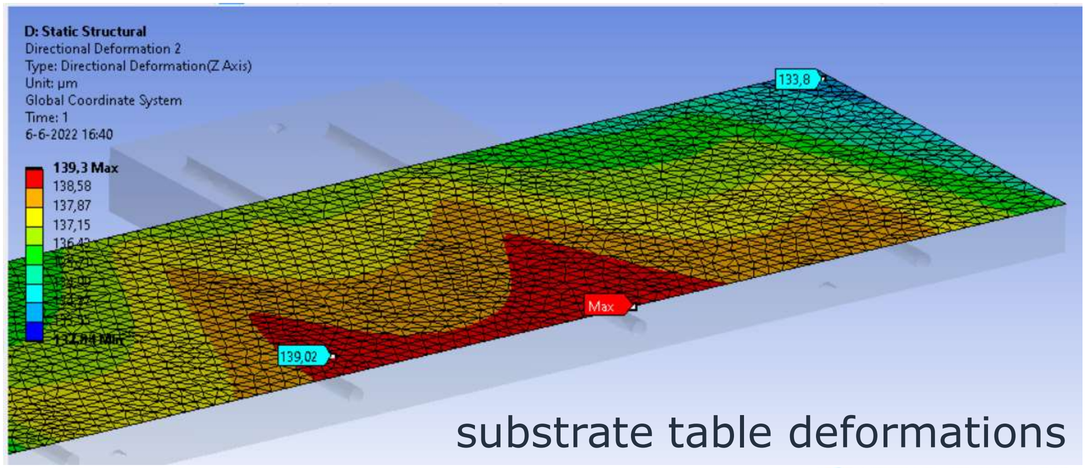
Steps taken to improve:

- Substrate table and injector head made of aluminium instead of stainless steel
- Insulation added around injectorhead and substrate table
- Heat losses by mechanical interfaces (e.g. supports, nuts and bolts) minimized by choosing materials with low thermal conductivity

Results:

- Substrate table deformations reduced a factor 100 compared to non-insulated stainless steel table
- by using materials with a low thermal conductivity for the mechanical supports a standard linear stage can be used

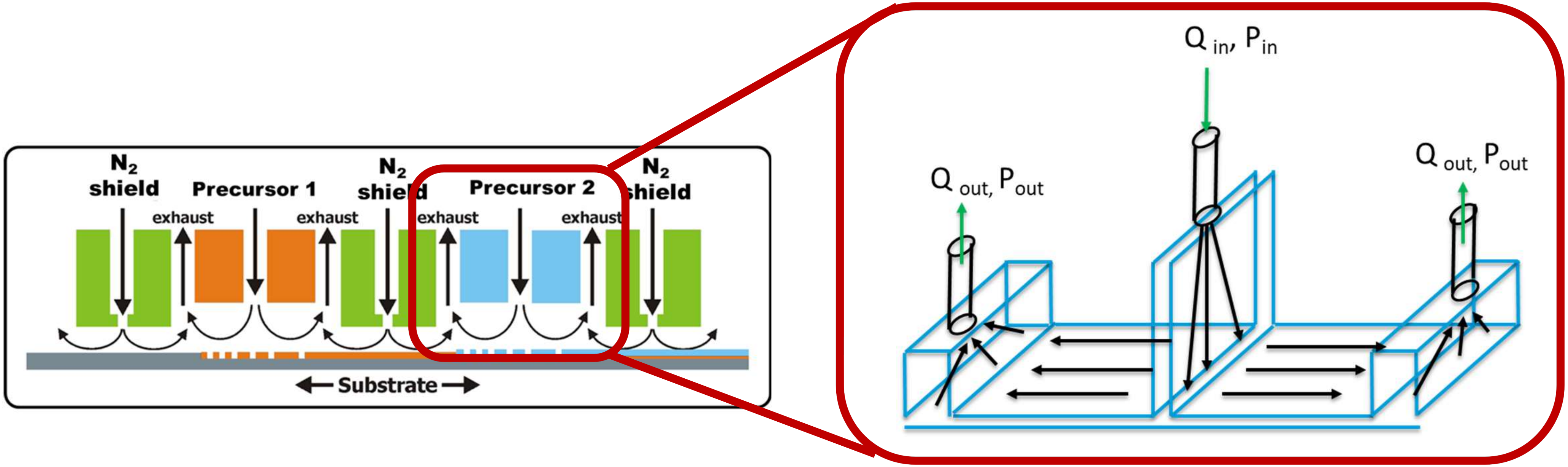




SPARKNANO

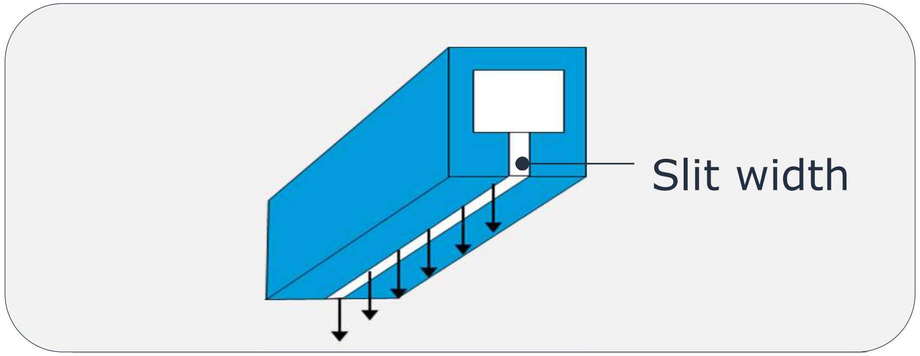
Gas flow uniformity

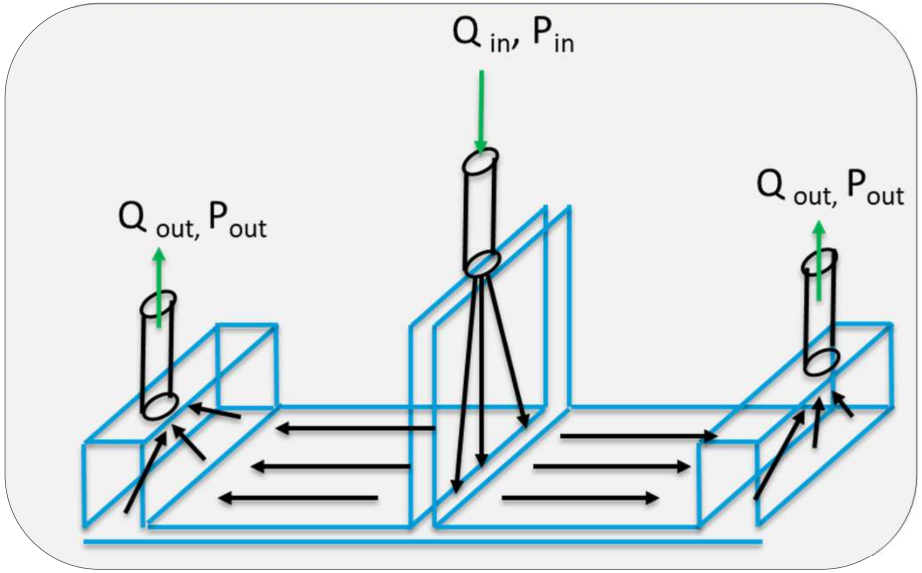
- A high film thickness uniformity is important for many Spatial ALD applications
- Non-uniform gas flows carrying precursors can lead to thickness non-uniformity
- Therefore, we need to distribute gasses as uniformly as possible



Gas flow uniformity

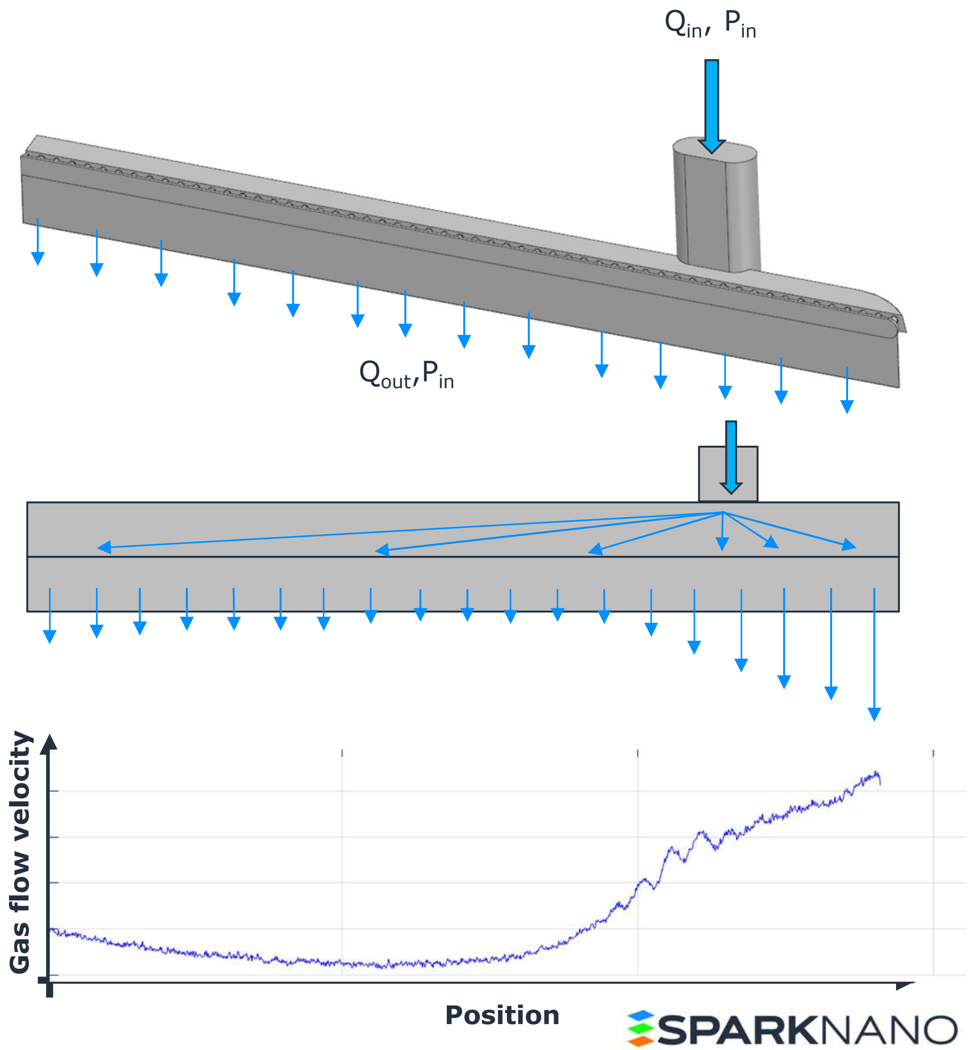
- Many Spatial ALD injectors use large pressure distribution chambers in combination with narrow slits
  - Narrow slits have a large flow restriction, so should help to evenly divide flows, just like in your showerhead at home
- However, making long narrow slits for large area Spatial ALD is not that easy; there will be manufacturing tolerances.
  - achieving an accuracy of +/-10 micron on a slit with a width of 100 micron is already a challenging accuracy
- As the flow through a slit varies as $Q \propto w^3$, a slit width variation of 10% results in flow variations of 33%!.





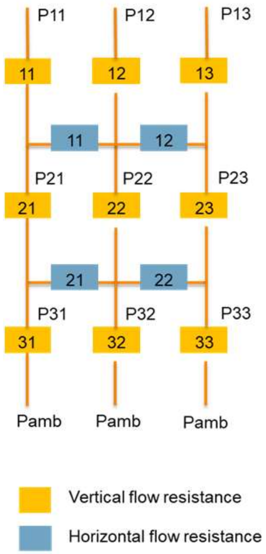
Gas flow uniformity

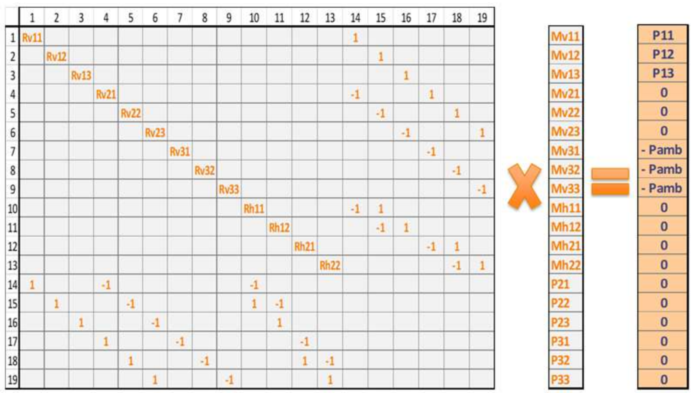
- Also, where you connect the injector to the gas lines matters
- An off-centred gas line connection can be desirable when space is limited, but can lead to large flow variations
  - There are many examples where the position of gas lines / exhaust lines can be “seen” on the substrate as areas with smaller or larger film thickness
- Computational Fluid Dynamics (CFD) modelling and network models can be used to check designs on flow uniformity



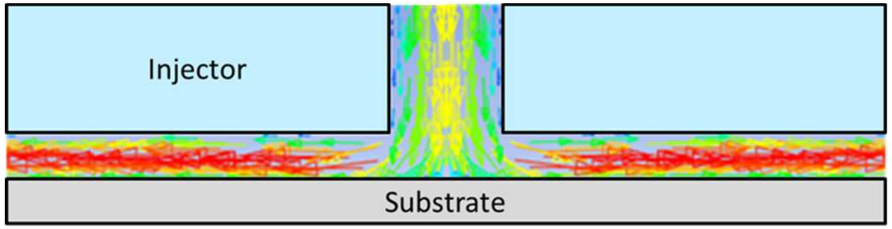
Modeling gas flows

- **Network models** are "quick and dirty" models which give a good first impression





- **CFD modelling** can be done using commercially available software
  - E.g. Fluent, ANSYS
- Outcomes include 3D information of pressure and flow variations based on injector design and selected boundary conditions
- Very valuable, but not always easy to do and time consuming



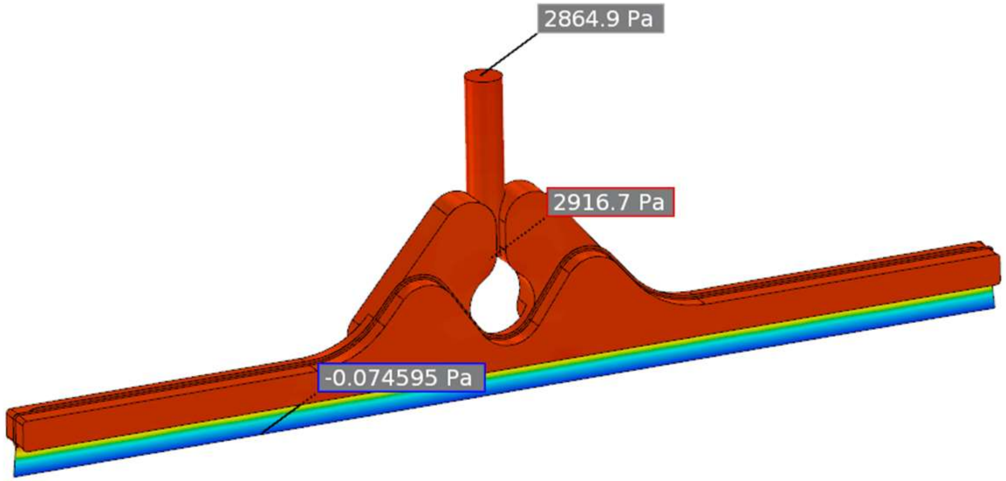
Gas flow uniformity

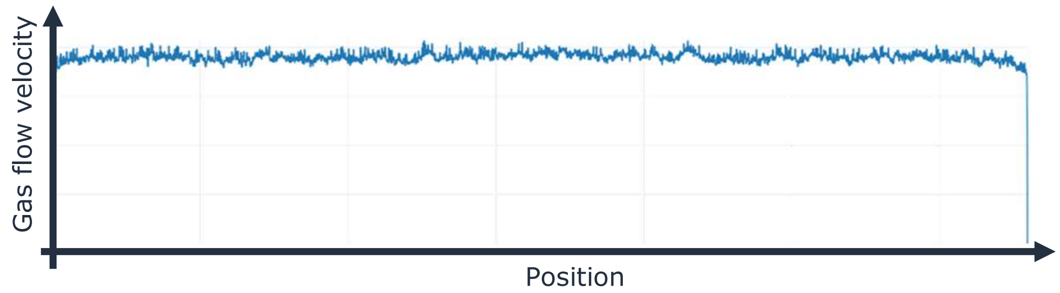
Steps taken to realize uniform gas flows:

- Use large pressure distribution chambers
- Make slit widths small enough to ensure uniform outflow within given tolerances
- Make first order calculation with network model and iterate design
- Perform CFD simulations as next step

Result:

Uniform gas flow distribution!





SPARKNANO

Summary and conclusions

- There are many design challenges mechanical engineers need to solve before a Spatial ALD tool can be used
- Thermo-mechanical deformations and gas-flow uniformity are just two examples
- Todays examples were simplified, but it does demonstrate our way of working:

1. Use customer requirements as a starting point
2. Use common sense and basic engineering knowledge to make mechanical designs
3. Evaluate designs using various modelling tools
    - From back-of-the-envelope to complex CFD and thermomechanical models
4. Improve the design, re-do step 3 until confident
5. Build and test. **Now it’s up to the process engineers…**

SPARKNANO

Thank you for your attention!