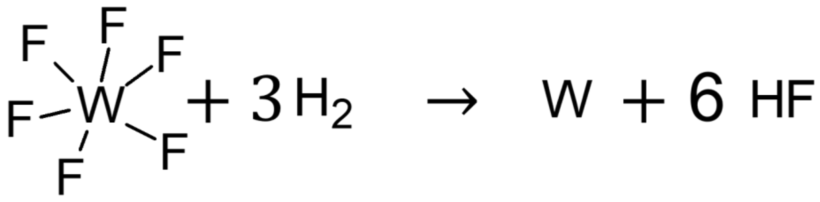
CVD Classroom slides 30 Oct 2024

Micro and Nanofabrication

Prof. hon. Martin A. M. Gijs

Chemical Vapour Deposition or CVD

- Chemical reaction is involved
- Example for deposition of W at high temperature (600 ºC)



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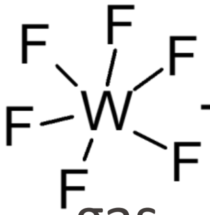

$$+ 3H_2 \rightarrow W + 6\,HF$$

gas gas solid gas

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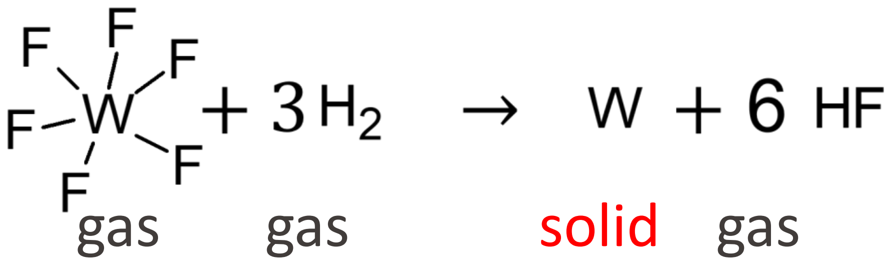
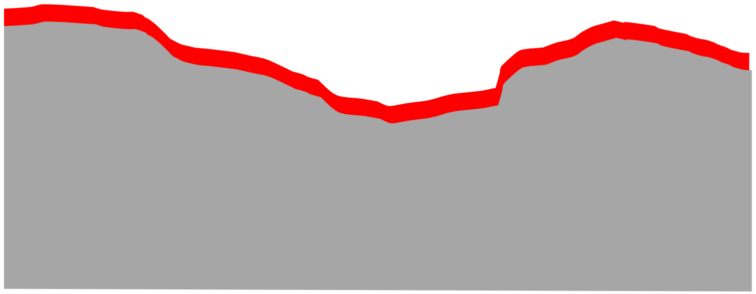


- Use of gaseous phase results in conformal deposition on substrate with arbitrary texture



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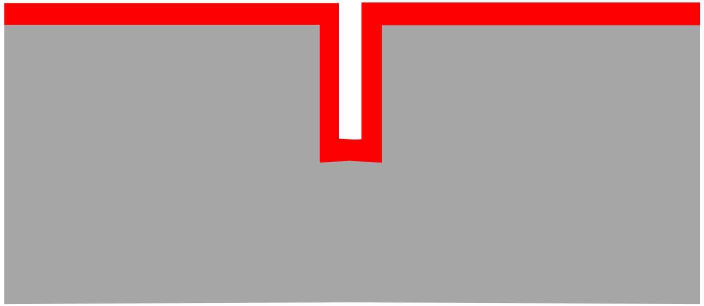

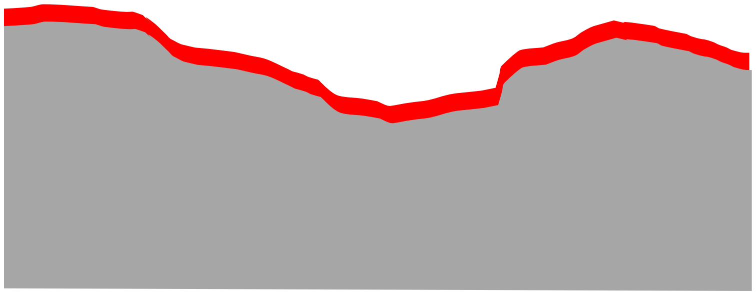

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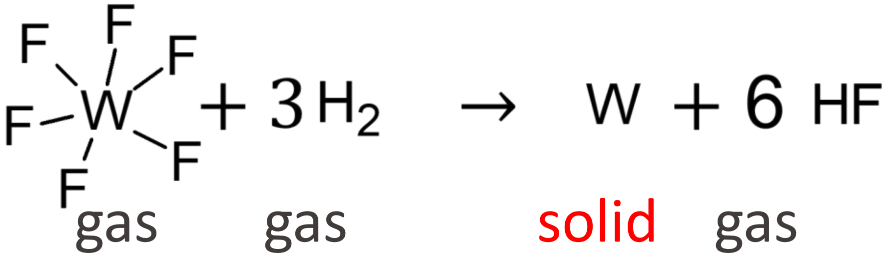

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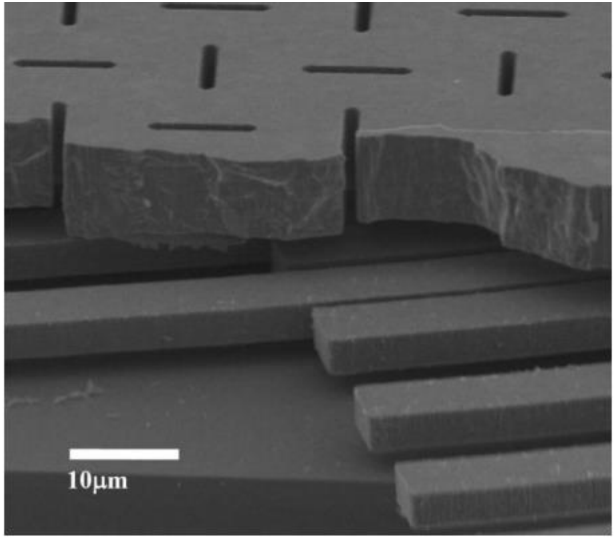

Fig. 11. SEM cross section showing released but unsealed interdigitated comb-drive fingers.

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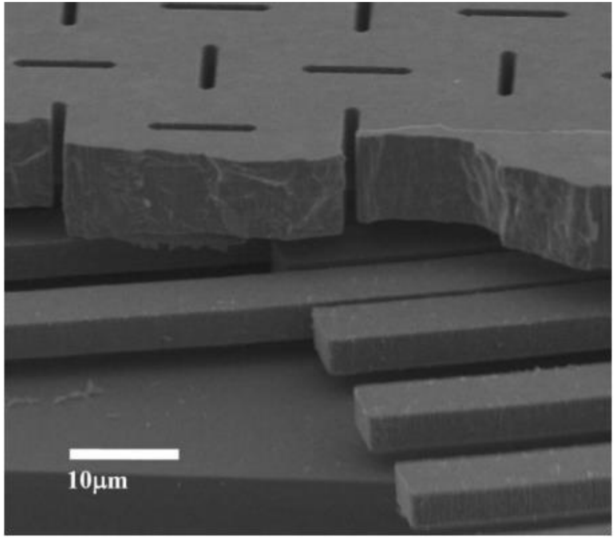


Fig. 11. SEM cross section showing released but unsealed interdigitated comb-drive fingers.

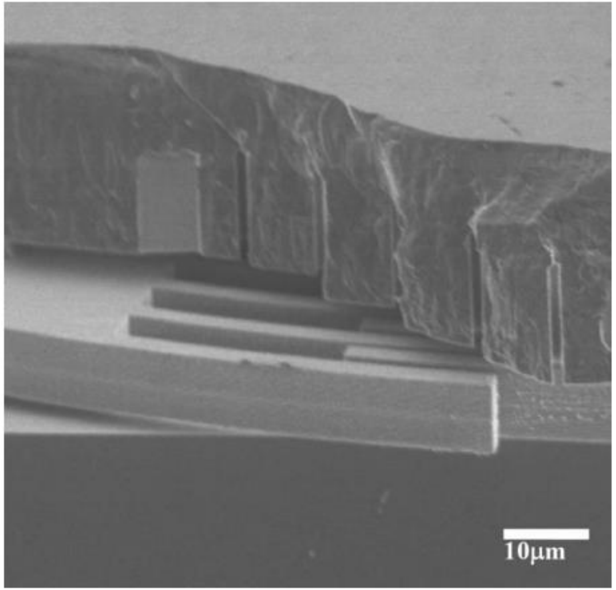


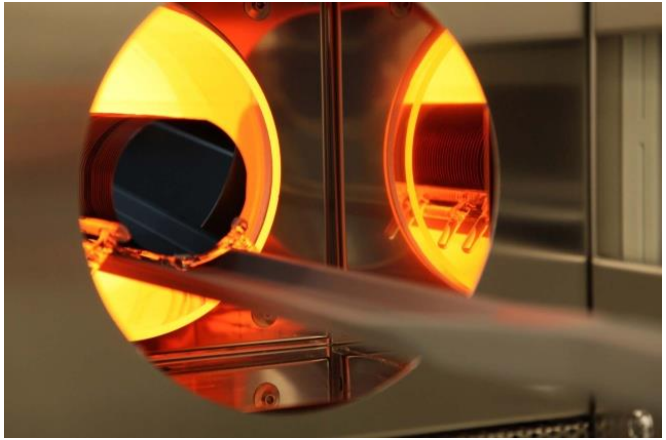
Fig. 12. SEM cross section showing encapsulated and sealed interdigitated comb-drive fingers.

Deposition of SiO_2 by CVD

CVD equipment

Example of a thermal CVD reactor

CVD equipment



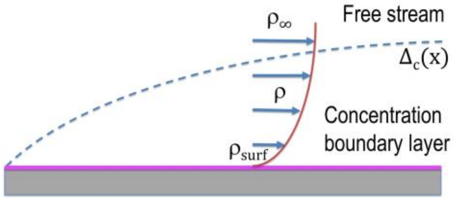
- A batch of Si wafers is positioned in a fused silica holder
- After closing of entrance port, the carrier gas enters the deposition chamber under very controlled flow and temperature conditions
- The CVD thin film is grown on all exposed surfaces of the wafers

Mass transfer from gas phase to substrate

- At equilibrium, the concentration at the surface (y=0) is maintained at a uniform value $\rho_{surf} < \rho_{y=\infty}$ and the gas transfer rate per unit surface can be written <u>in three dimensions</u> as

$$\dot{N}[m^{-2}s^{-1}] = h[m\,s^{-1}]\left(\rho_{surf} - \rho_{y=\infty}\right)[m^{-3}]$$

with h the mass transfer coefficient



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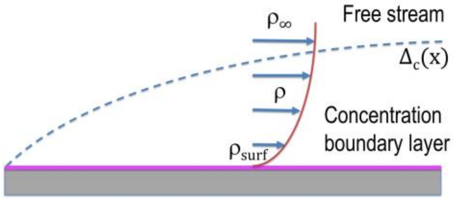


with h the mass transfer coefficient

- If mass flux associated with species transfer is by **diffusion, Fick's law** applies at the surface

$$\dot{N} = -D\left.\frac{\partial\rho}{\partial y}\right|_{y=0} \qquad h = \frac{-D\left.\frac{\partial\rho}{\partial y}\right|_{y=0}}{\left(\rho_{surf} - \rho_{y=\infty}\right)}$$

Calculation of the film growth rate

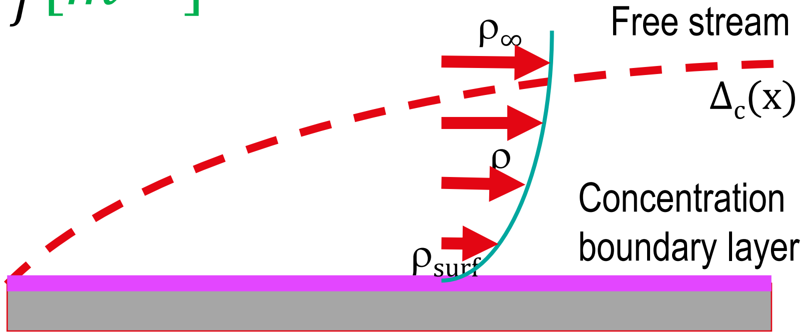
- Diffusion flux of molecules through the boundary layer

$$\dot{N}_1\,[m^{-2}s^{-1}] = h\,[m\;s^{-1}]\left(\rho_{surf} - \rho_{y=\infty}\right)[m^{-3}]$$

- Flux of reacted molecules consumed by the surface reaction

$$\dot{N}_2\,[m^{-2}s^{-1}] = -k_{surf}\,[m\;s^{-1}]\,\rho_{surf}\,[m^{-3}]$$

with k_{surf} the surface reaction rate



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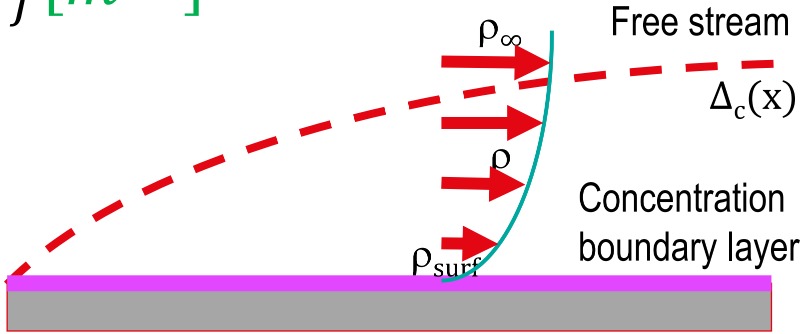
$$\dot{N}_2\,[m^{-2}s^{-1}] = -k_{surf}\,[m\,s^{-1}]\rho_{surf}\,[m^{-3}]$$

with k_{surf} the surface reaction rate

- In equilibrium, $\dot{N} \equiv \dot{N}_1 = \dot{N}_2$, giving

$$\rho_{surf} = \rho_{y=\infty}\left(\frac{h + k_{surf}}{h}\right)^{-1}$$



- The film growth rate is then proportional to

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- If $h \gg k_{surf}$, we have the surface reaction-controlled case and

$$\dot{N} = k_{surf} \, \rho_{y=\infty}$$

EPFL

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$$\dot{N} = \frac{k_{surf} h}{h + k_{surf}} \rho_{y=\infty}$$

- If $h \gg k_{surf}$, we have the surface reaction-controlled case and

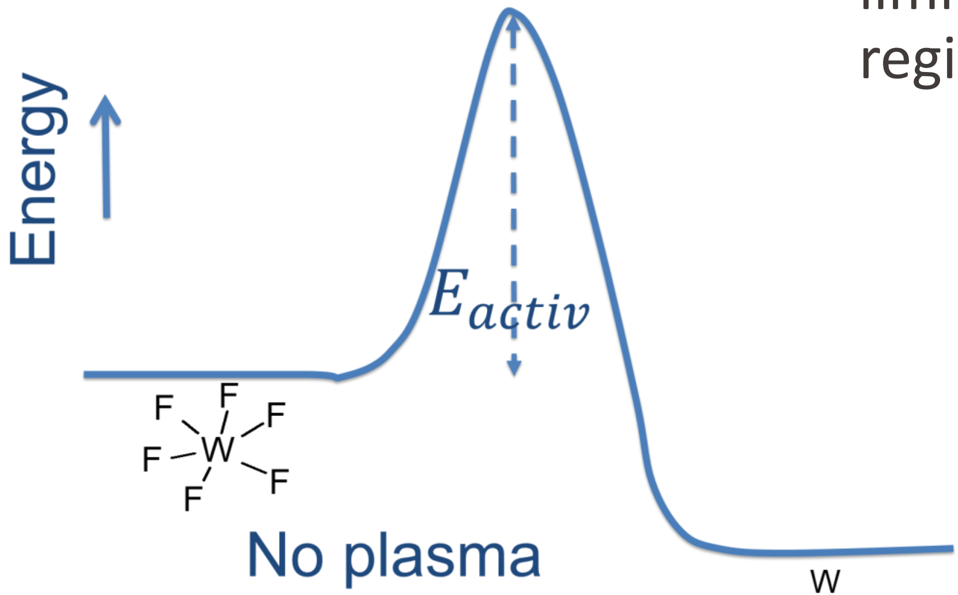
$$\dot{N} = k_{surf} \, \rho_{y=\infty}$$

- If $h \ll k_{surf}$, we have the diffusion-controlled case and

$$\dot{N} = h \, \rho_{y=\infty}$$

EPFL

$$k_{surf} \sim e^{-\frac{E_{activ}}{k_B T}}$$



Temperature decides whether film growth is in the reaction-limited or gas diffusion-limited regime

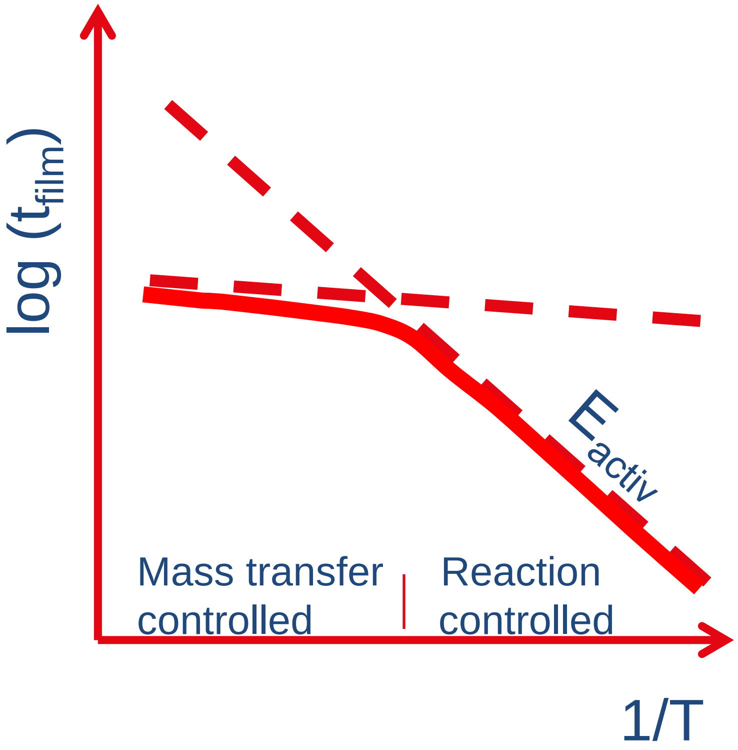
EPFL

$$t_{film}(x) = C_{gas}(x) \times P_{growth} \times e^{-\frac{E_{activ}}{k_B T}}$$

$$k_{surf} \sim e^{-\frac{E_{activ}}{k_B T}}$$

- At high temperature, growth is in the mass transport-limited regime → control of gas flow and pressure is crucial for obtaining uniform films
- At low temperature, growth is in the reaction-limited regime → control of local temperature is crucial for obtaining uniform films
- A low gas pressure is beneficial for good film uniformity and step coverage
-

Arrhenius plot of the film growth rate



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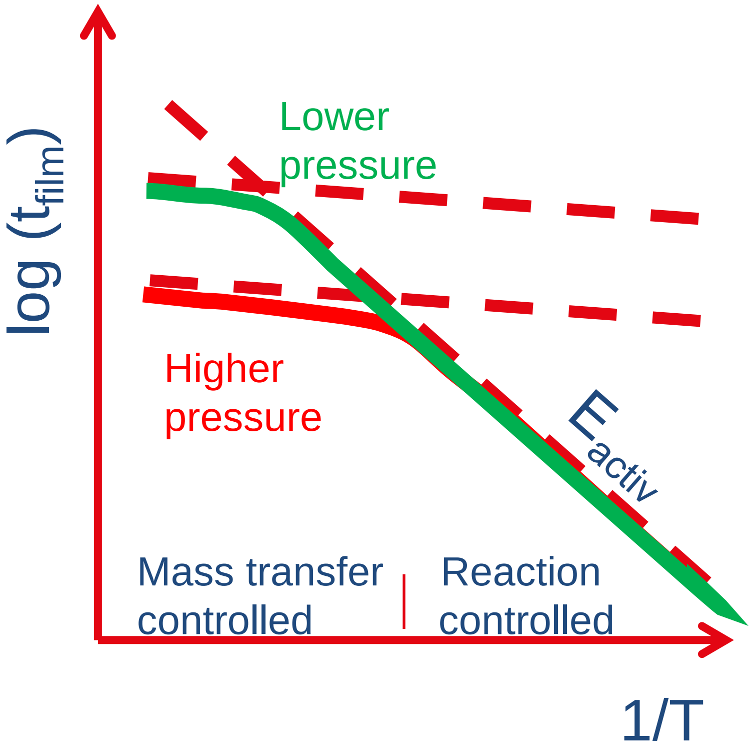
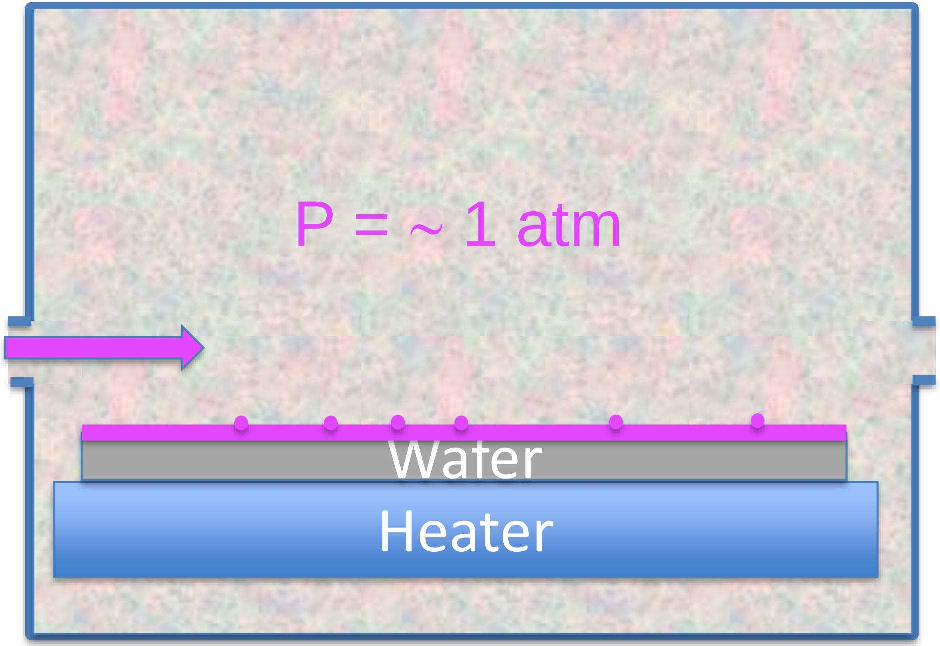
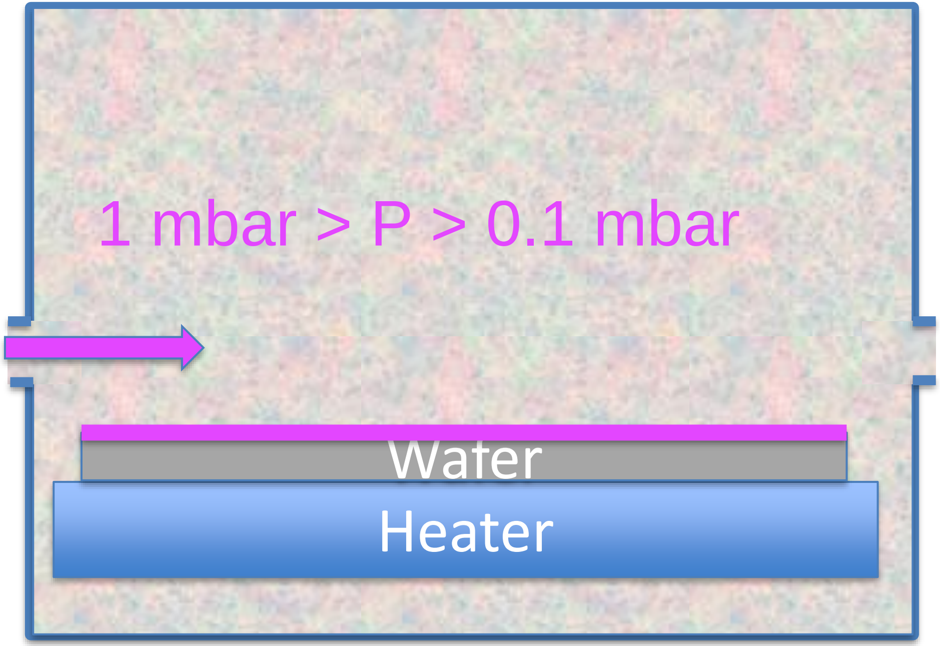


Atmospheric pressure CVD (APCVD)



- At high temperature, growth is in the mass transport-limited regime → gas flow control is very important
- Wafer placed horizontally in the gas flow → limits throughput
- Reaction may already start in the gas phase, resulting in unwanted precipitates on the wafer → non-uniformities or pinholes in deposited film

Low-pressure CVD (LPCVD)



- Low pressure results in increased gas diffusion
- No gas concentration gradient perpendicular to flow direction
- More uniform films
- 400 ºC < T < 900 ºC
- Growth in reaction-limited regime
- Precise temperature control is important
- Usually 10-100 × lower deposition rates compared to APCVD

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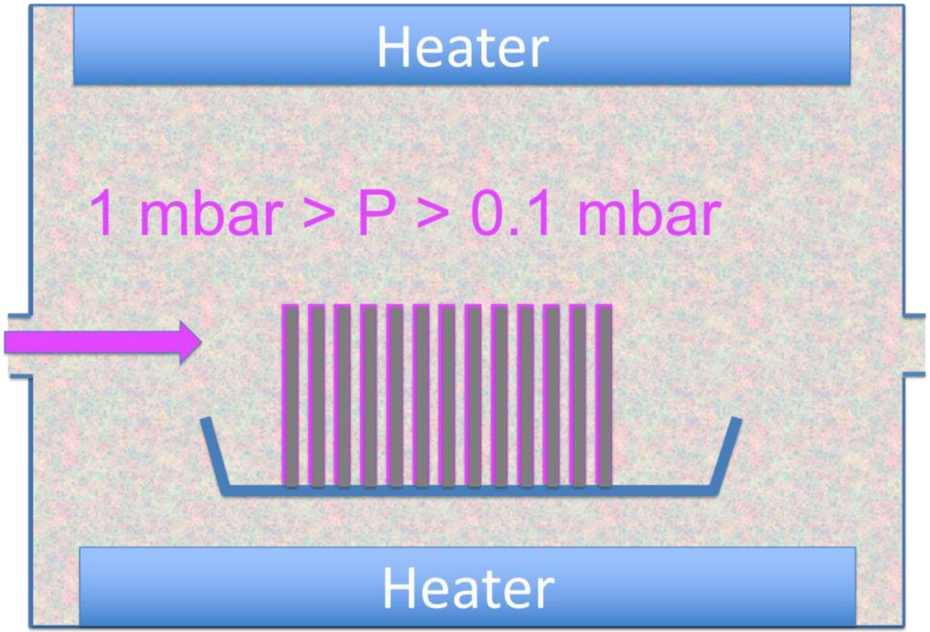
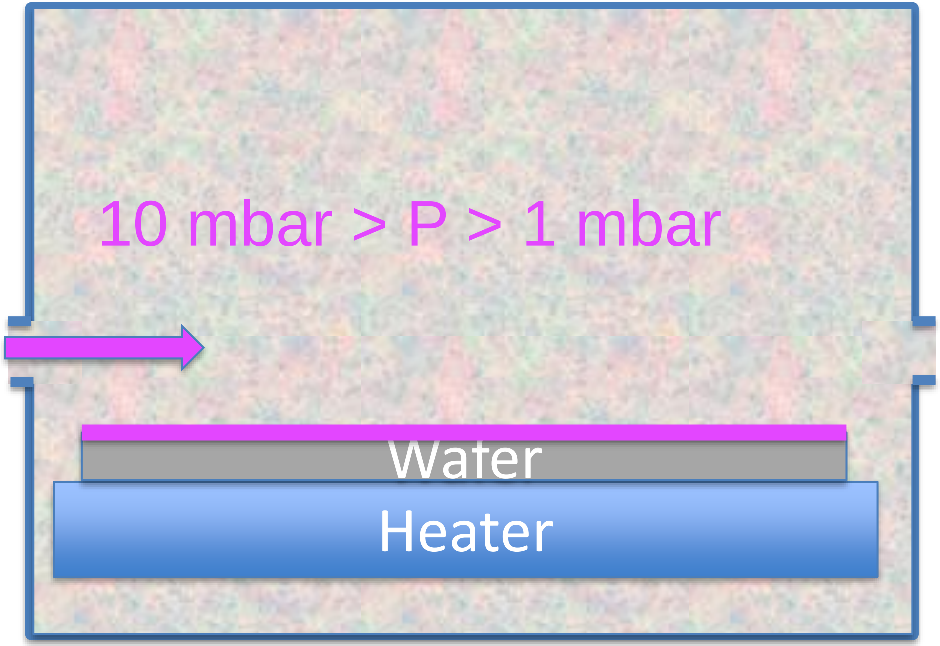


- Wafers can be stacked vertically in batches due to homogeneous gas conditions →
  wafer throughput can be enhanced
- Downstream depletion of gases can be compensated by establishing a temperature gradient in the heater system

Plasma-enhanced CVD (PECVD)



- Based on LPCVD-like configuration

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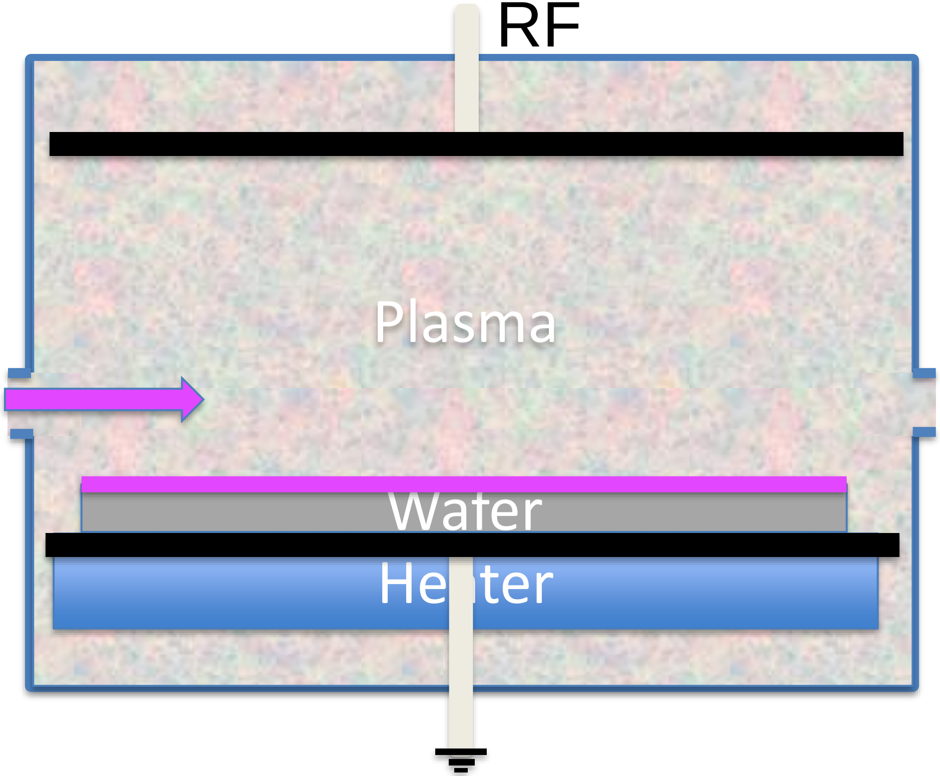

- Based on LPCVD-like configuration
- Radio Frequency (RF) power coupled into the gas, typically at 400 kHz or 13.56 MHz
- RF power induces plasma, i.e. a partially ionized gas, containing ions, electrons and excited gas molecules