

# Content

## 3. Specific Processes for Advanced Micro- and Nanoelectronics

- 3.1 Specific CVD Processes
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- 3.3 Advanced PVD Processes
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- 3.6 Advanced Lithography
- 3.7 Advanced Dry/Plasma Etching Processes
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- 3.9 Electrochemical Deposition and Electroless Deposition

## **3.1 Special CVD Processes**

- 3.1.1 Metal CVD (W, Cu)
- 3.1.2 Metal Nitride CVD - Conductive Diffusion Barriers
- 3.1.3 Applications of CVD poly-Si, SiO<sub>2</sub>, Si<sub>x</sub>N<sub>y</sub> ...
- 3.1.4 CVD of low-k dielectrics

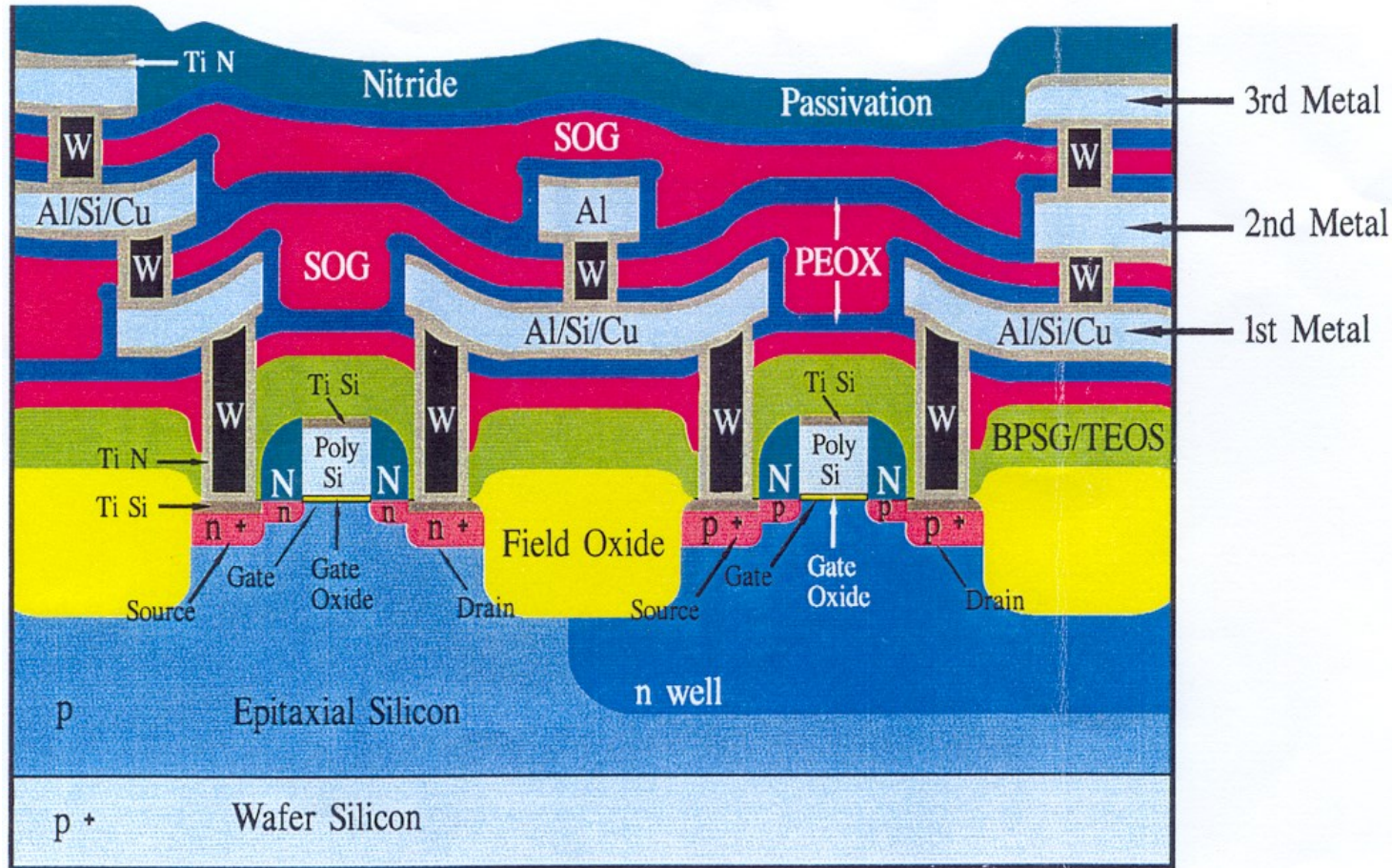
### **3.1.1 Metal CVD**

#### **(A) Tungsten (W) CVD**

- Application and integration aspects
- Precursors and reactions
- Process characteristics and film properties
- Selective process

## Application and integration aspects of CVD-W

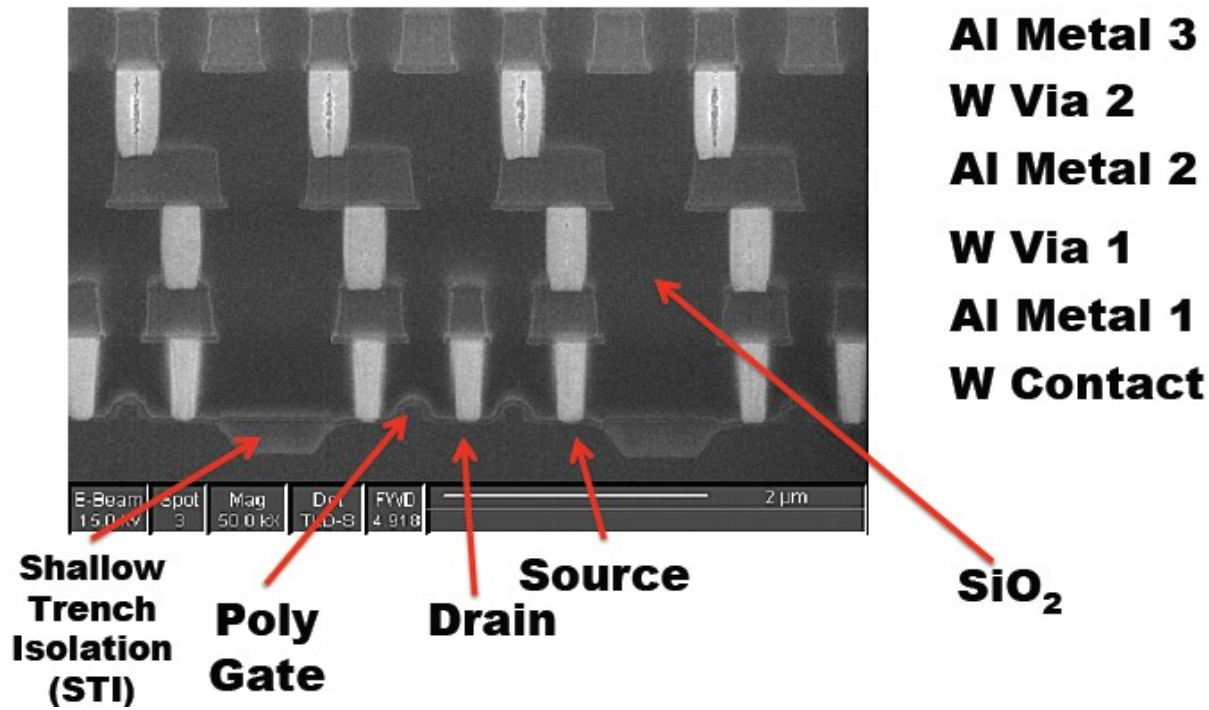
## Three Metal Layer CMOS Device



Source: PTI Seminars, Inc, 1749 Gilsinn Ln, St. Louis, MO 63026

## Application and integration aspects of CVD-W

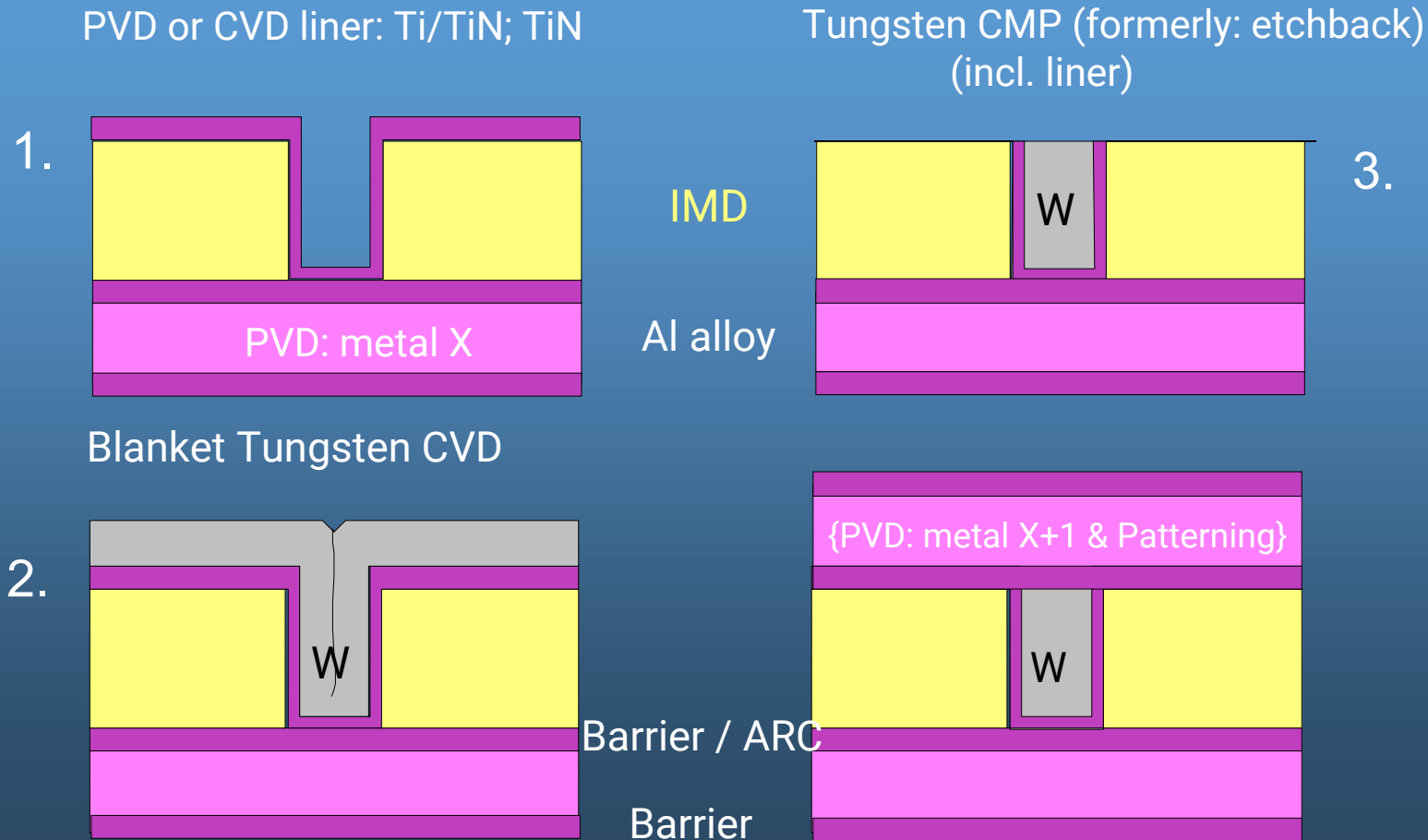
### TSMC 0.18 CMOS Cross Section



Source: Course on VLSI design  
Peter Kogge, Joseph Nahas (University of Notre Dam)

## CVD Tungsten Via Fill: Process sequence („W plug“)

Tungsten via fill (W plug) using blanket W-CVD (contact fill accordingly)



## Tungsten CVD: Precursors

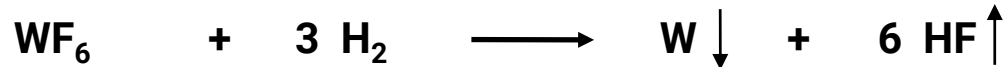
Precursor	Phase (@RT, air pressure)	vapour pressure
$\text{WF}_6$	gaseous	880 Torr (21 °C)
$\text{WCl}_6$	solid	0.7 ... 7 Torr (150...200 °C)
$\text{W}(\text{CO})_6$	solid	10 ... 50 mTorr (30 °C)
metalorganic		

### **Tungsten deposition using $\text{WF}_6$ is very sensitive to the wafer surface materials:**

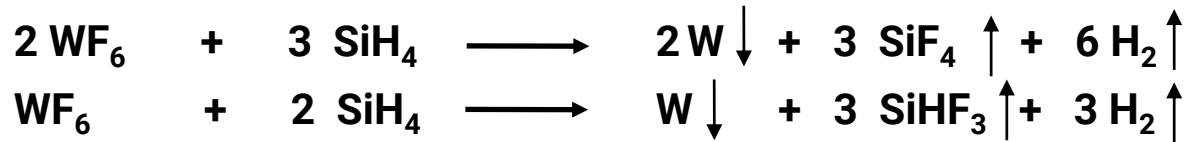
- faster nucleation on metallic and conducting surfaces
- bad nucleation and adhesion on insulators
- liner for blanket deposition required
- selective deposition mode possible

## Tungsten CVD: Reactions

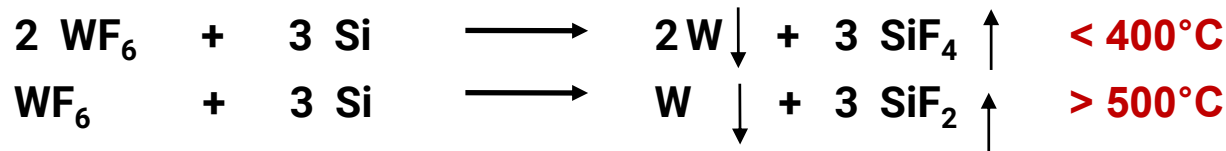
*Hydrogen reduction of  $WF_6$ : blanket W deposition for contact and via fill*



*Silane reduction of  $WF_6$ : nucleation step for blanket W CVD selective deposition for contact or via fill*



*Silicon reduction of  $WF_6$ : parasitic reaction during contact fill on Si*



*Aluminium reduction of  $WF_6$ : parasitic reaction during via fill*

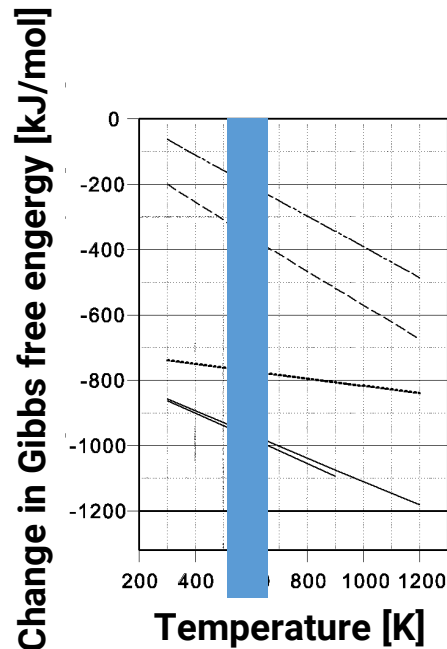


$AlF_3$  increases via resistance: liner as barrier against  $WF_6$  diffusion required



## Tungsten CVD:

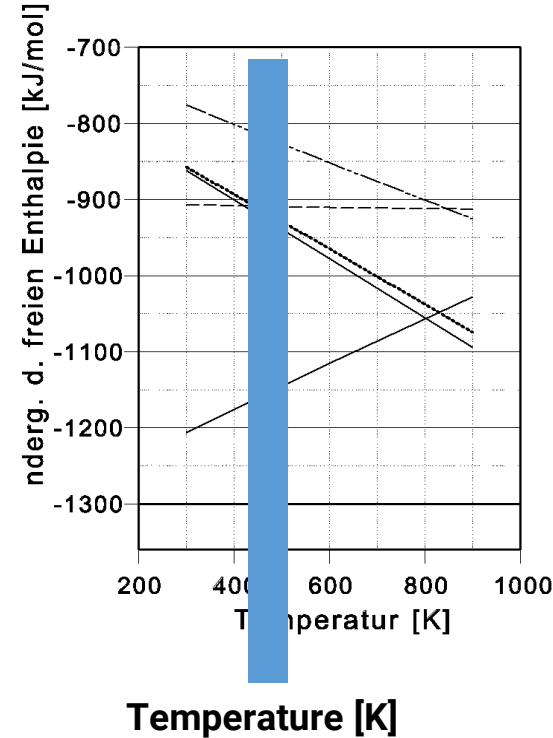
### Reactions - Thermodynamic considerations



### Reduction reactions on Si

- H<sub>2</sub>-Red.
- Si-Red. (SiF<sub>2</sub>)
- Si-Red. (SiF<sub>4</sub>)
- SiH<sub>4</sub>-Red. (SiF<sub>4</sub>)
- SiH<sub>4</sub>-Red. (SiHF<sub>3</sub>)

### Change in Gibbs free energy [kJ/mol]



### Reduction reactions on Al

- Al [AlF<sub>3</sub> (g)]
- Al [(AlF<sub>3</sub>)<sub>2</sub> (g)]
- SiH<sub>4</sub> [SiF<sub>4</sub>/H<sub>2</sub>]
- SiH<sub>4</sub> [SiHF<sub>3</sub>/H<sub>2</sub>]
- Al [AlF<sub>3</sub> (s)]



## Tungsten CVD: Process characteristics

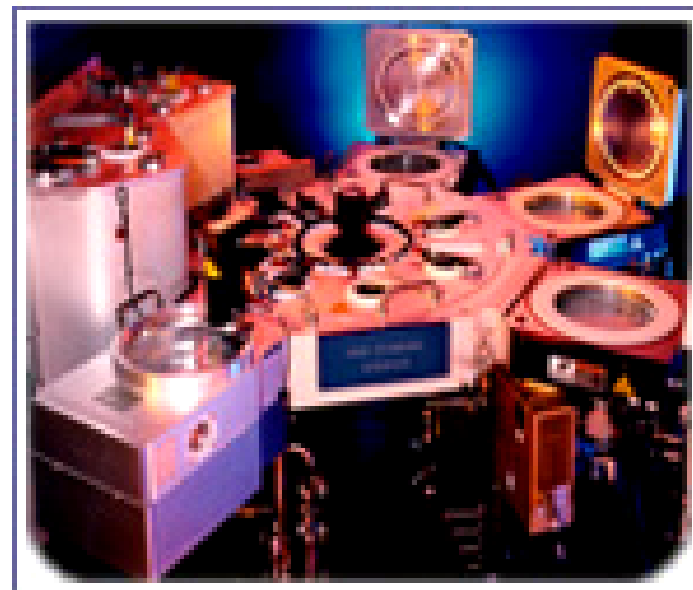
### Nucleation step:

- $\text{SiH}_4$  /  $\text{WF}_6$
- Low p (e.g. 5 Torr)

### Main deposition:

- $\text{H}_2$  /  $\text{WF}_6$
- High pressure 80...300 Torr
- 375...470°C

- Chamber clean between deposition
- Plasma or remote microwave
- Increases MWBC (wet clean)
- F-based chemistry with following  $\text{H}_2$  clean



### Temperature effect ( $T \downarrow$ :)

- resistivity  $\uparrow$
- step coverage  $\uparrow$
- deposition rate  $\downarrow$

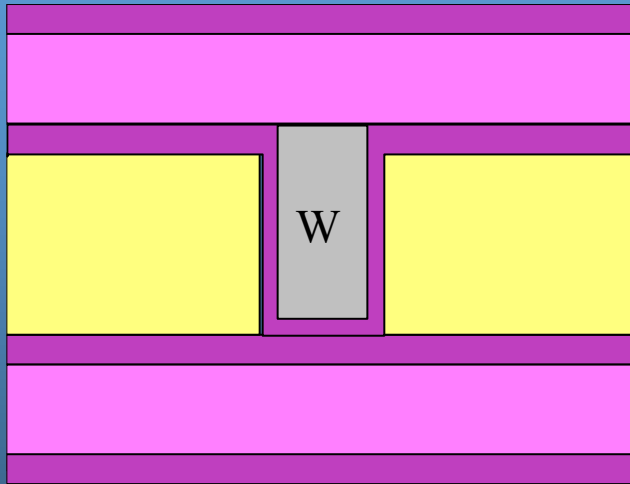
## Tungsten CVD: Film properties

Parameter	Via Fill	Interconnect
W Thickness	500 nm	350 nm
Bulk resistivity	< 11.5 $\mu\Omega\text{cm}$	< 10.5 $\mu\Omega\text{cm}$
film reflectance ( bei 480 nm)	60%	70%
Stress $T_{\text{dep}} = 440^\circ\text{C}$	1.5 GPa	1.5 GPa
$T_{\text{dep}} = 375^\circ\text{C}$	1.9 GPa	1.9 GPa
Step coverage		
0.25 $\mu\text{m}$ , 8:1 AR $T_{\text{dep}} = 375^\circ\text{C}$	90%	NA
0.30 $\mu\text{m}$ , 5:1 AR $T_{\text{dep}} = 440^\circ\text{C}$	90%	NA
Sheet resistance uniformity		
WIW ( $1\sigma$ )	< 2%	< 2%
WTW ( $1\sigma$ )	< 2%	< 2%

Source: Applied Materials (<http://appliedmaterials.com/products>)

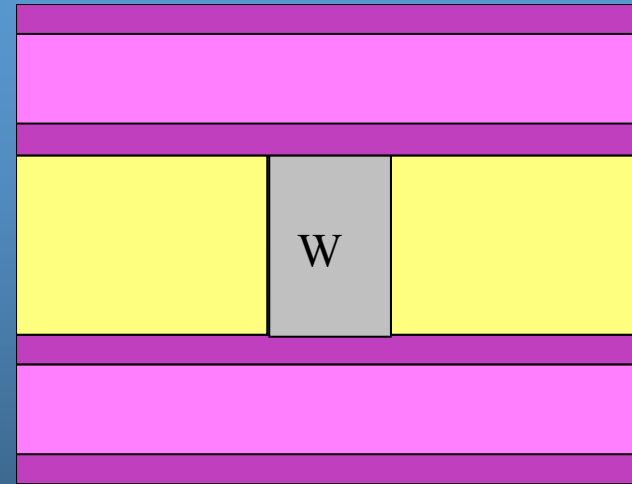
## Tungsten CVD: Selective deposition

### Blanket Tungsten CVD



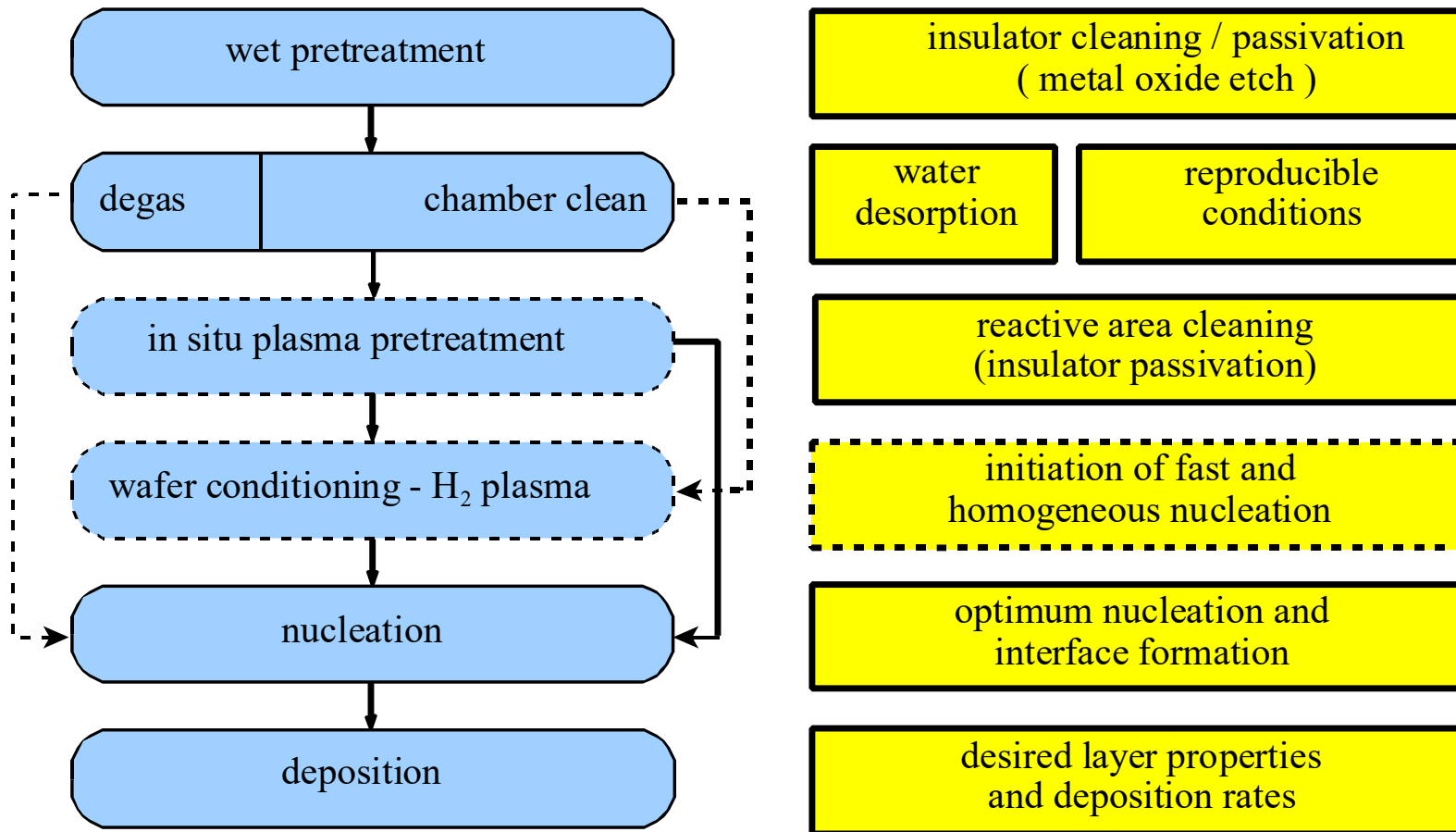
Via clean  
Liner deposition  
W CVD  
W CMP

### Selective Tungsten CVD



Via clean  
W CVD

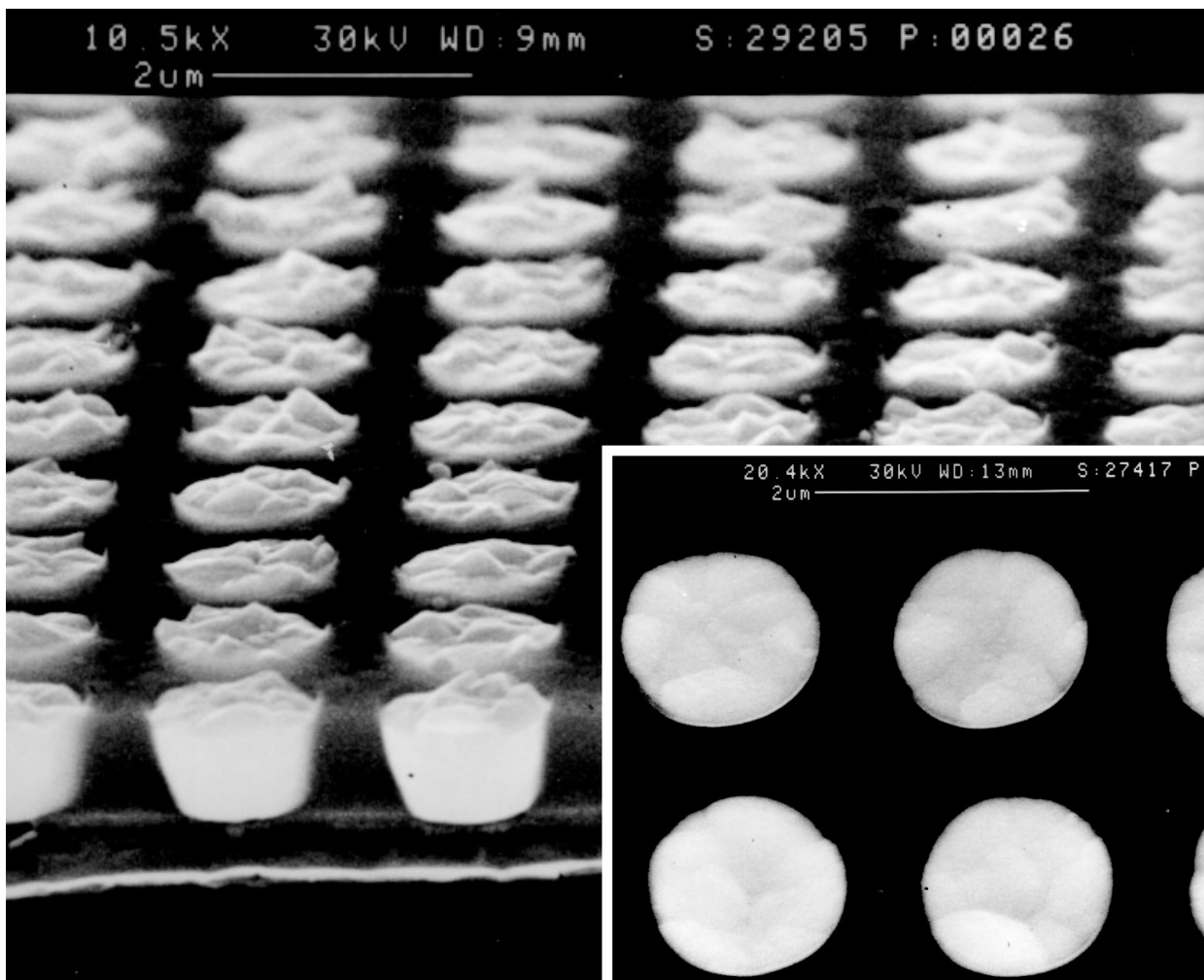
## Tungsten CVD: Selective deposition



**required process steps depend on  
reactive area material (e.g. Al, TiN)**

Source: S.E. Schulz, PhD thesis, TU Chemnitz, 1996

## Tungsten CVD: Selective deposition



Source: S.E. Schulz, PhD thesis, TU Chemnitz, 1996