



Welcome!

From Sub-nanometer to Micrometer Films, or how to Combine ALD with PVD

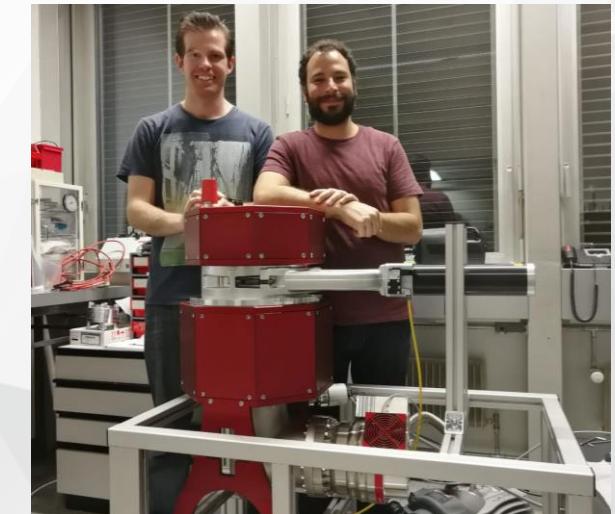
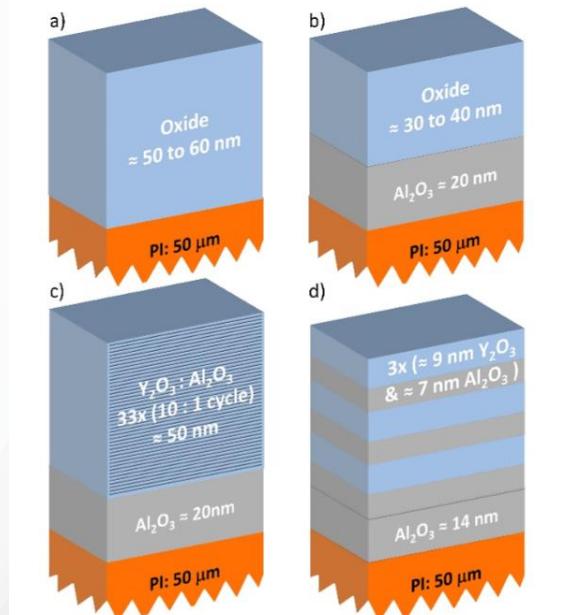
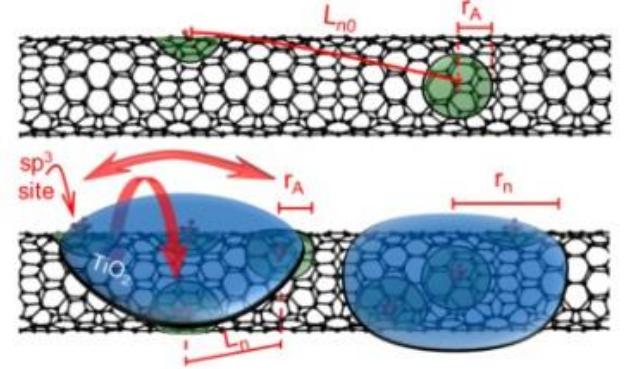
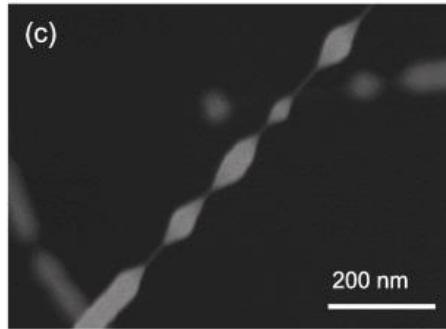
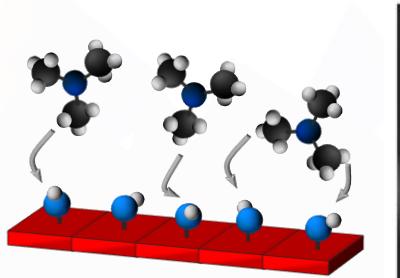
Dr. Carlos Guerra

- Berner Fachhochschule TI

ABOUT MYSELF



Materials Science and Technology



SWISS CLUSTER

spin off
F H Bern University
of Applied Sciences

Swiss Cluster
Materials, Science & Technology



Thun

spin-off | Empa

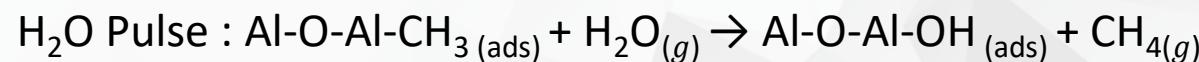
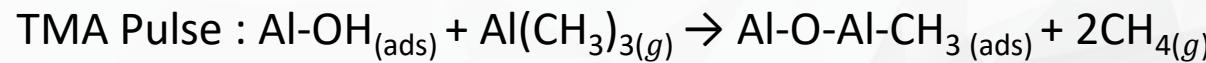
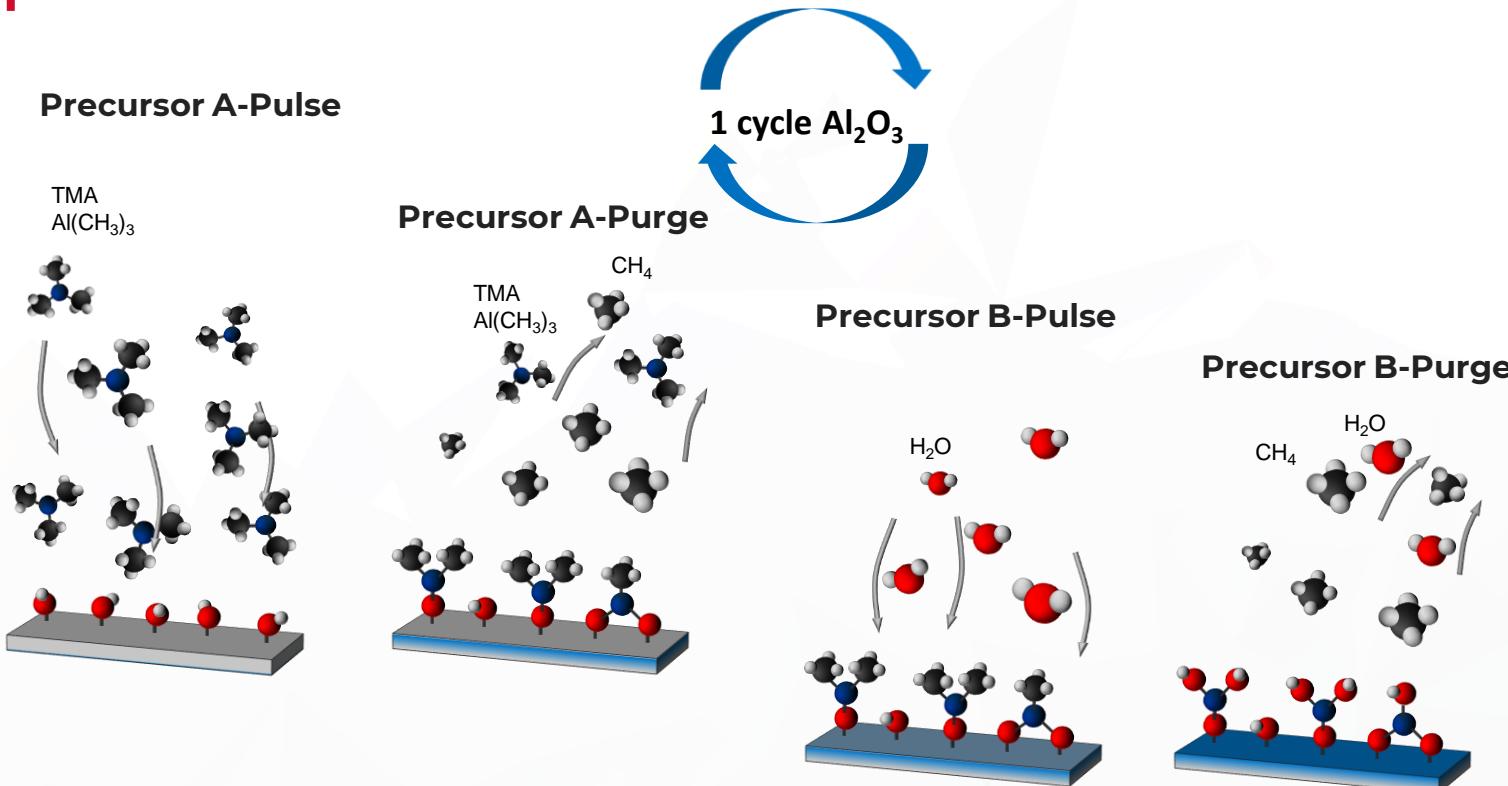


Nov. 2020
Swiss Cluster

OUTLINE

- Atomic Layer Deposition (ALD)
- Why ALD/PVD
- Swiss Cluster Equipment
- ALD /PVD multilayers

Thermal-ALD

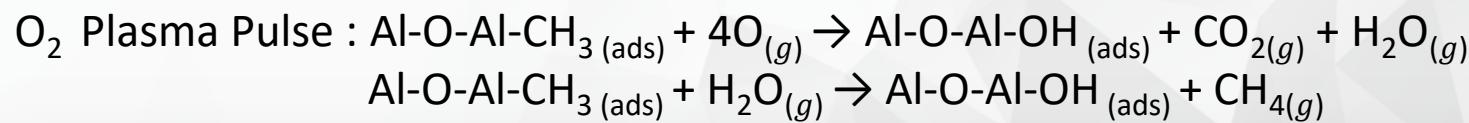
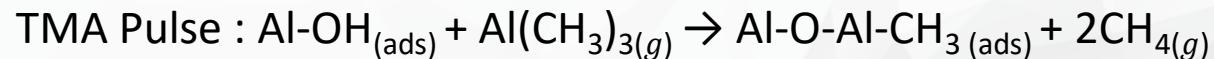
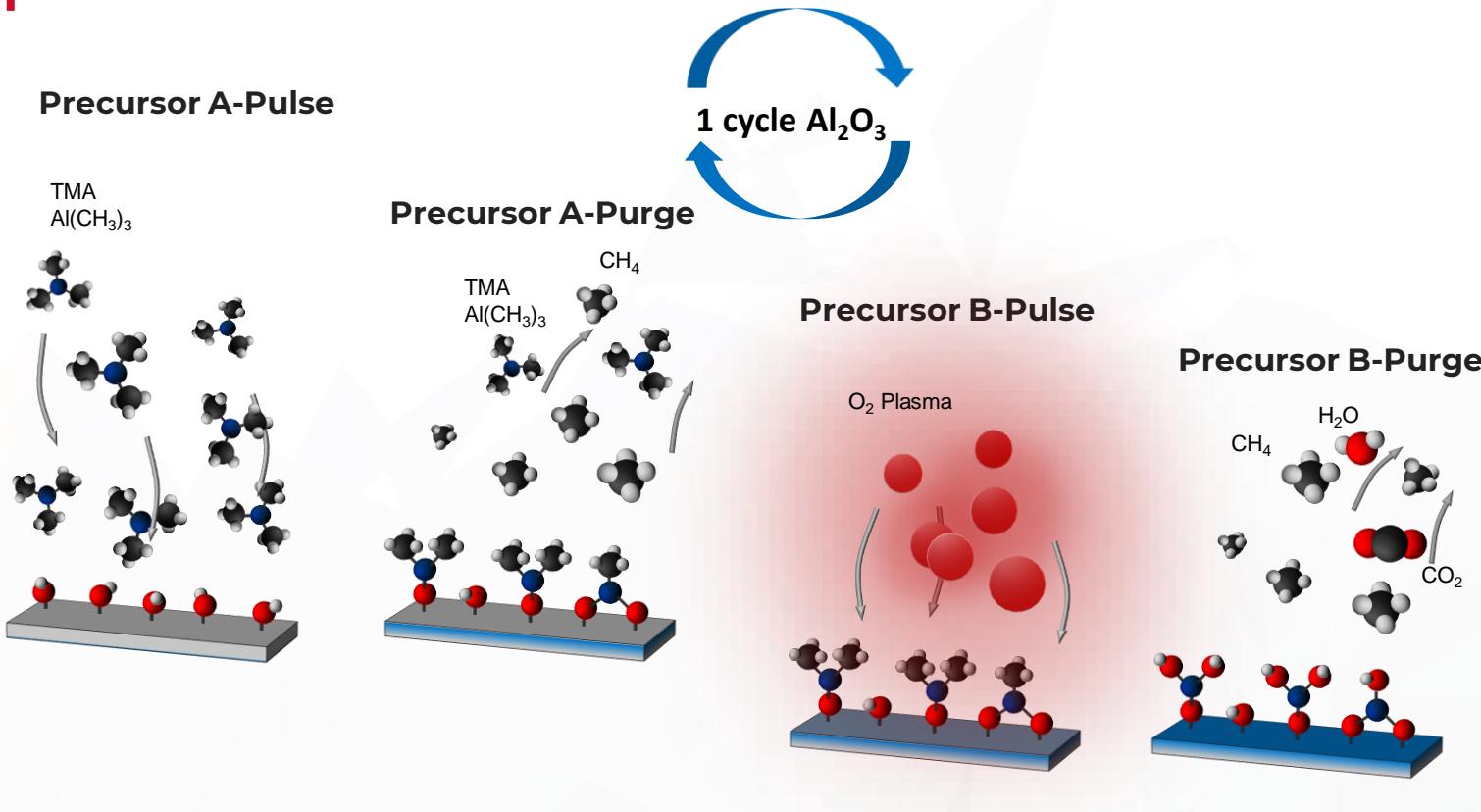


Thermal ALD

- Self-Limiting
- Conformal on AR
- “Pinhole-free”

2nd Precursors

- H_2O
- O_2
- O_3
- H_2
- NH_3
- H_2S



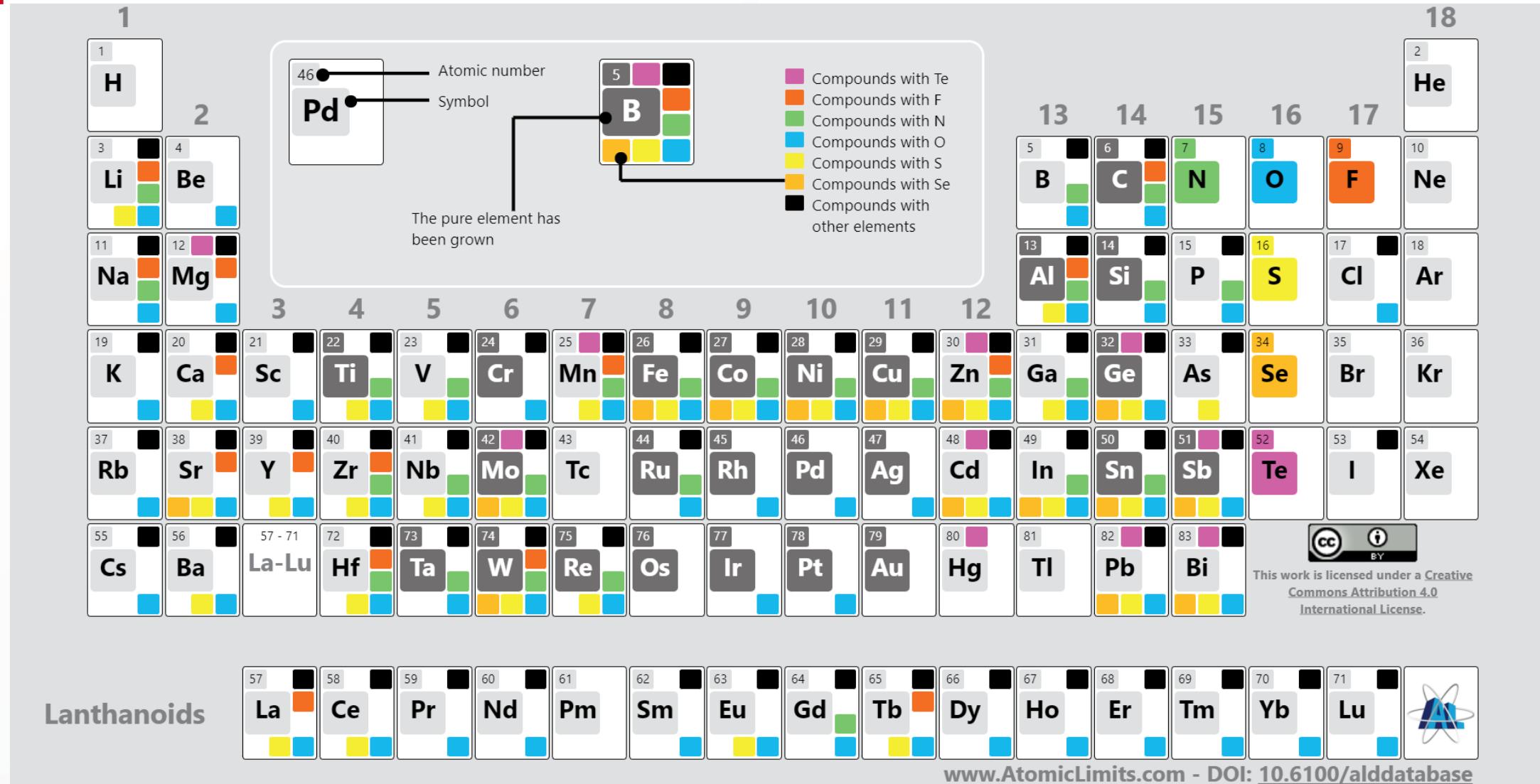
Plasma Enhanced-ALD

- ~Self-Limiting
- Conformal on 2D
- > “Pinhole-free”

2nd Precursor-Plasma

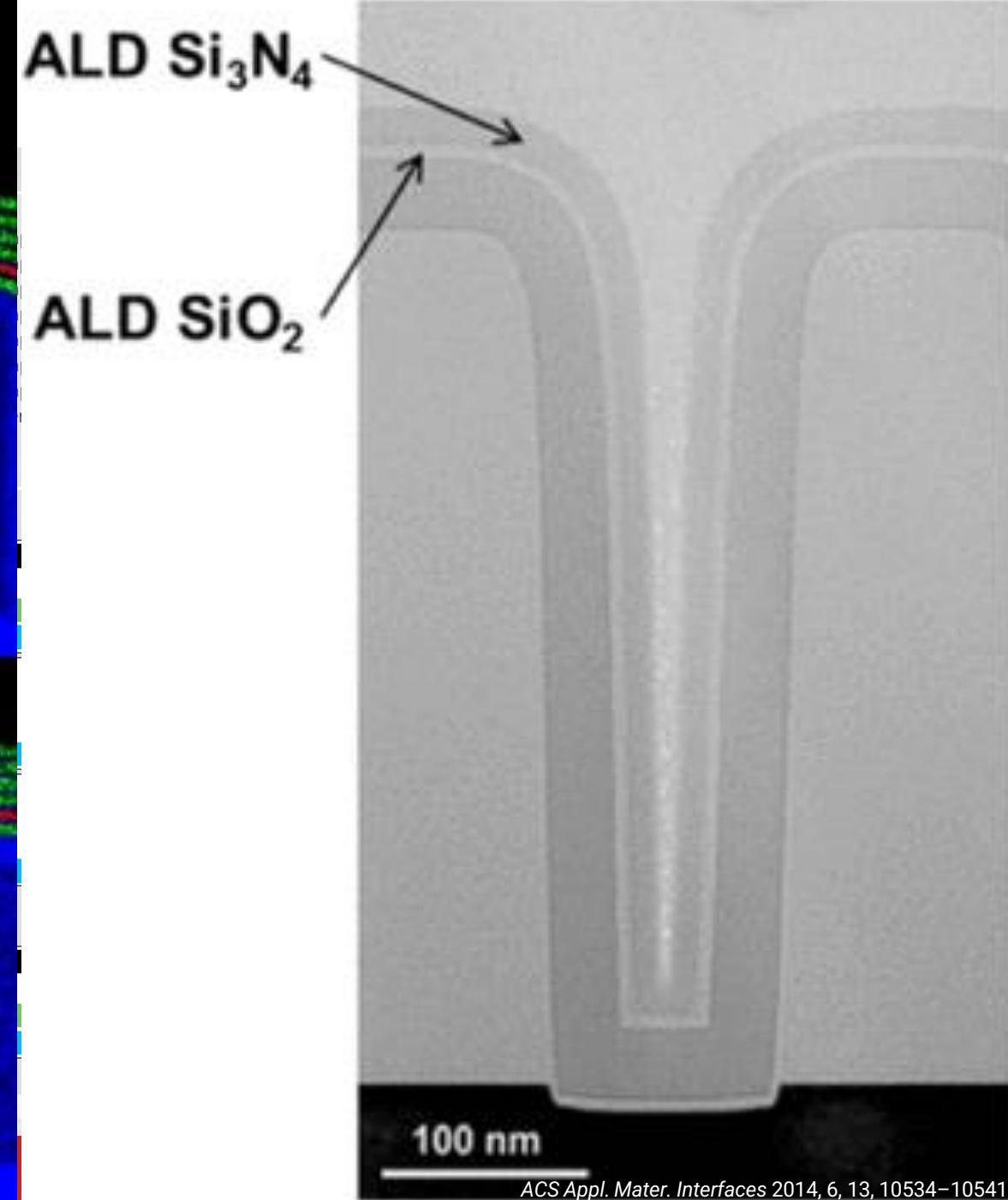
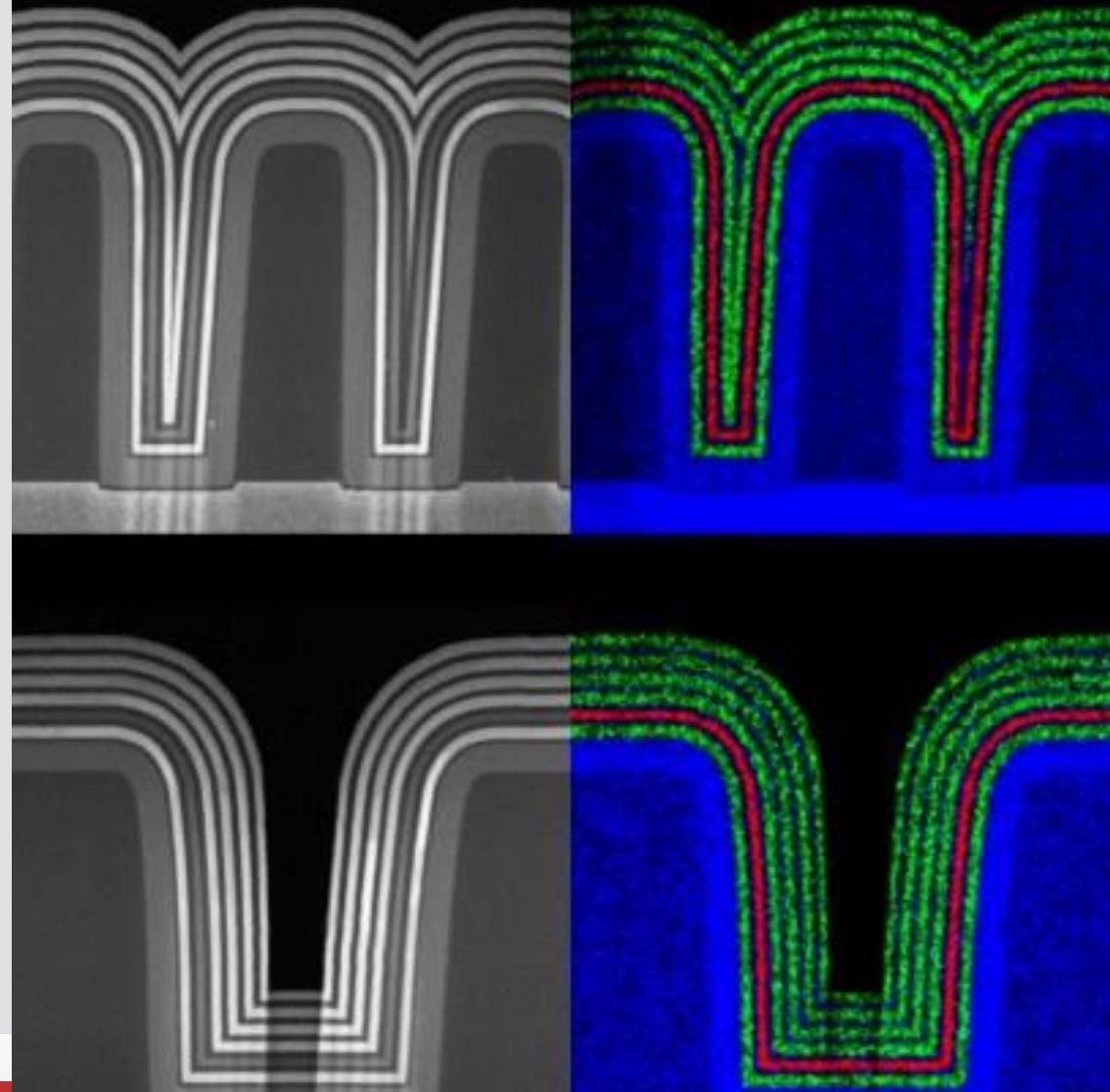
- O_2
- N_2
- H_2
- H_2O
- NH_3
- SF_6

ALD PERIODIC TABLE

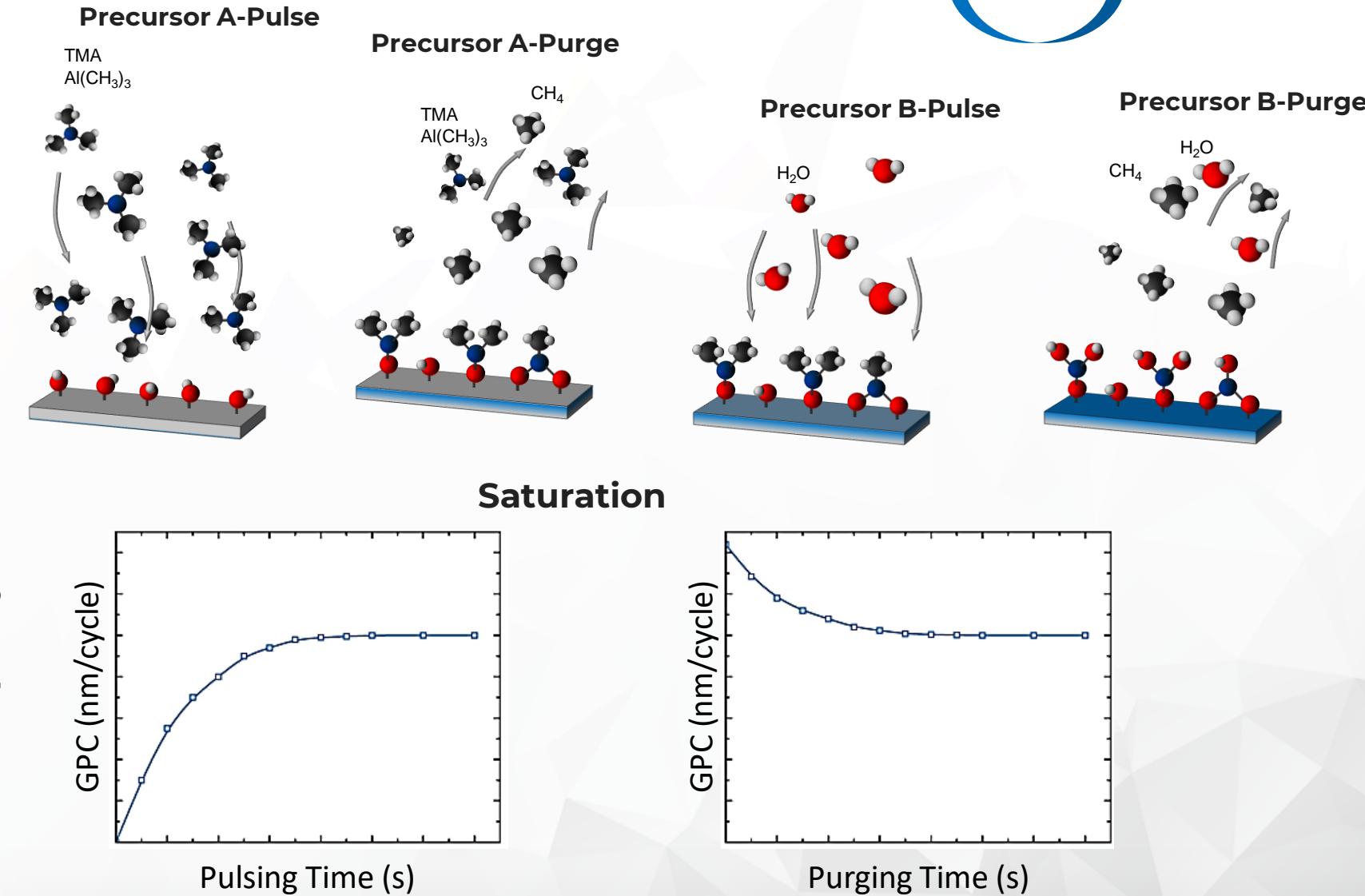


HAADF-STEM
200 nm

EDS
Ti Si Al



ALD PROCESS

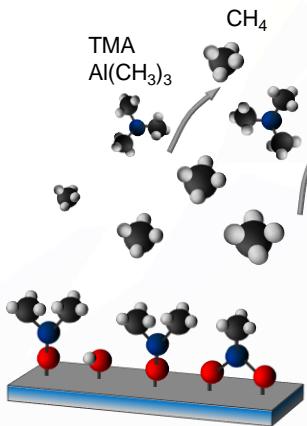


ALD PROCESS

Precursor A-Pulse

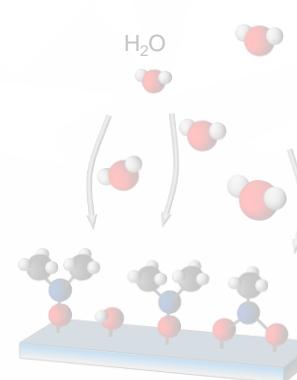


Precursor A-Purge

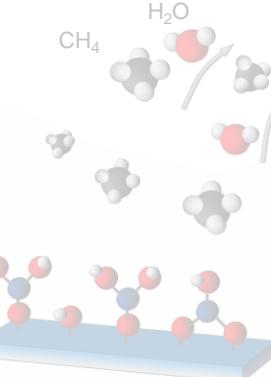


1 cycle Al_2O_3

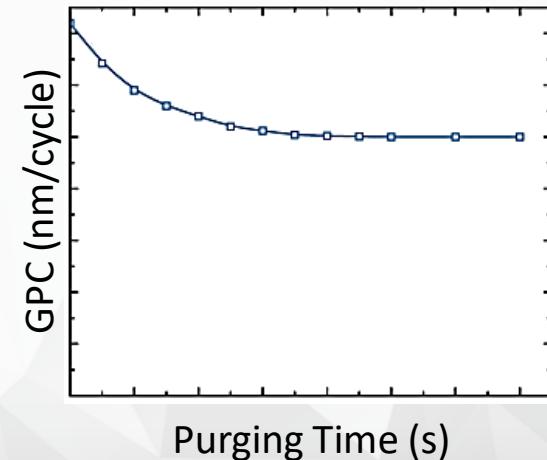
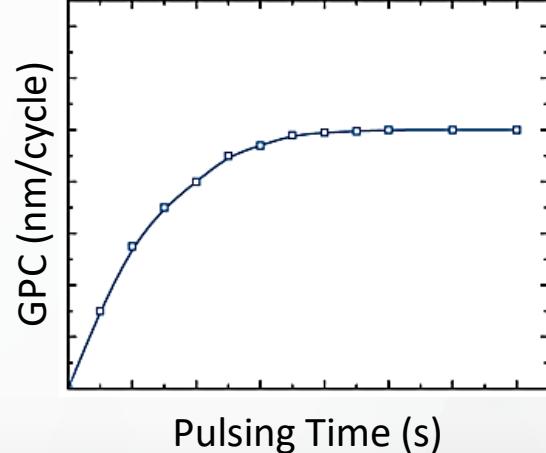
Precursor B-Pulse



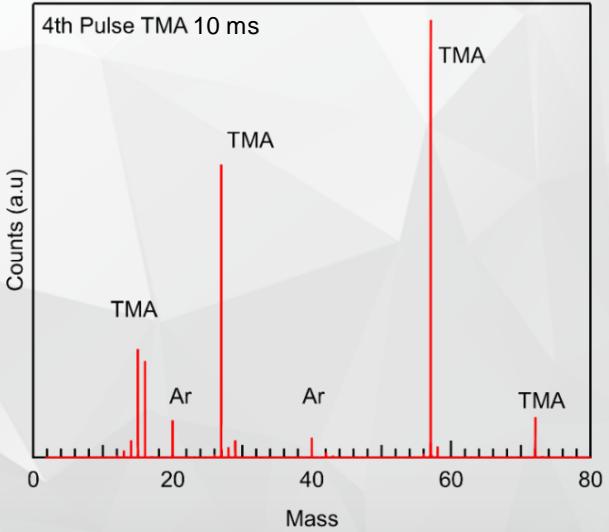
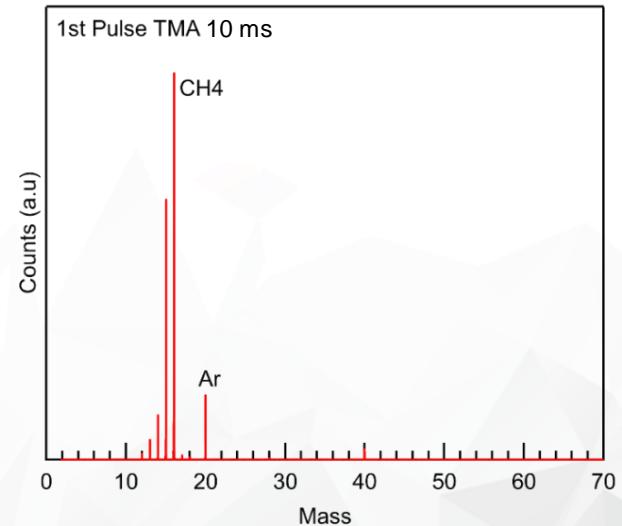
Precursor B-Purge



Saturation

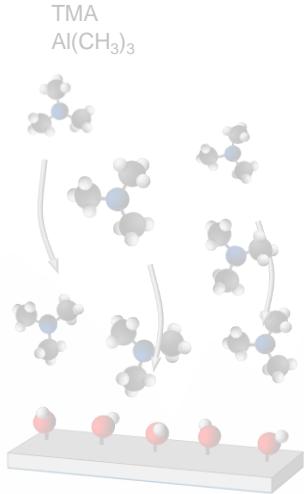


TOF- MS

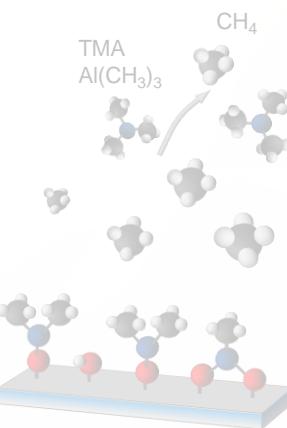


ALD PROCESS

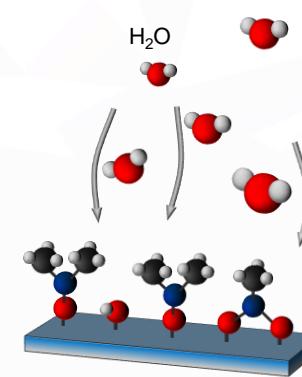
Precursor A-Pulse



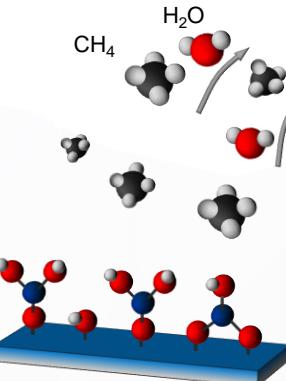
Precursor A-Purge



Precursor B-Pulse

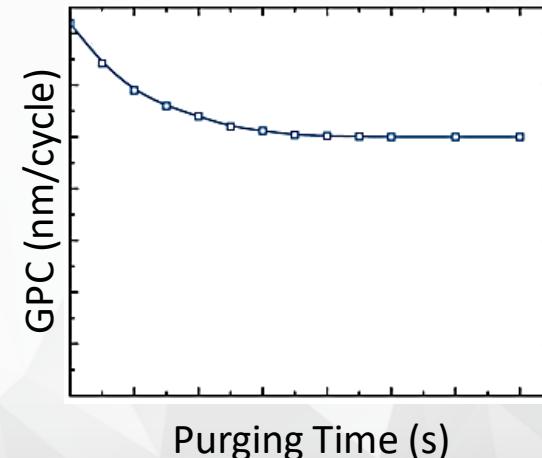
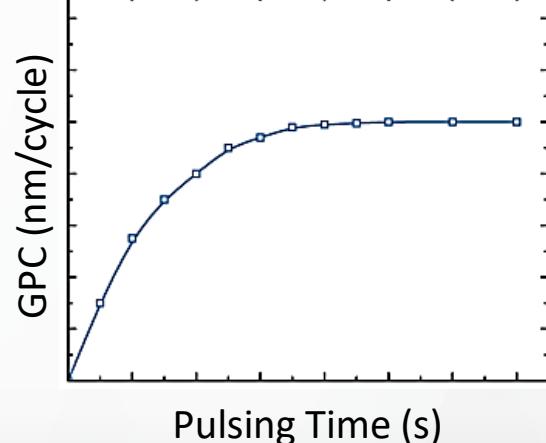


Precursor B-Purge

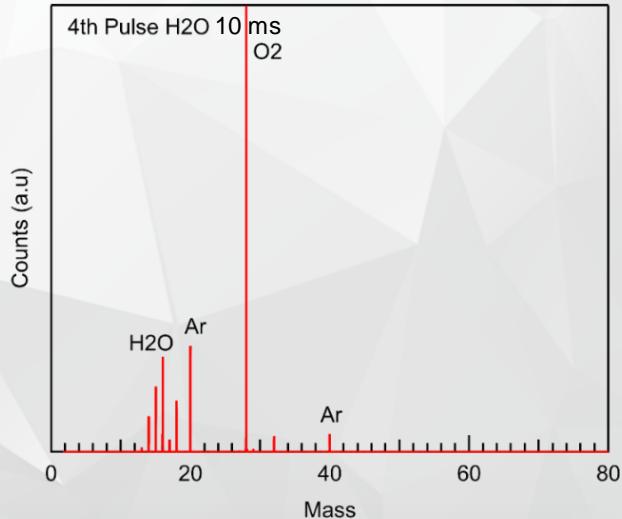
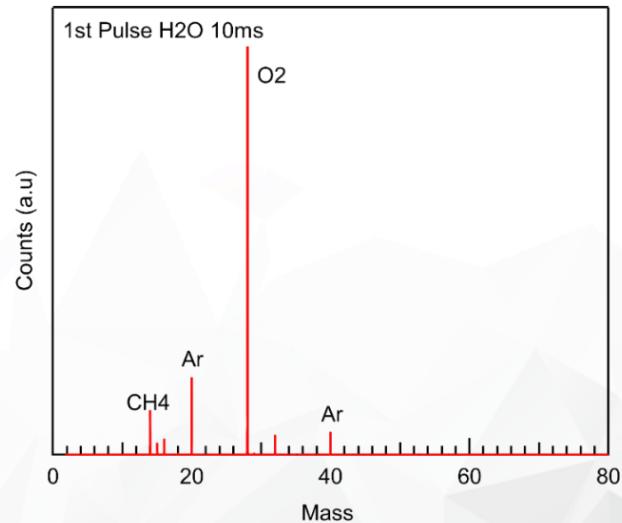


1 cycle Al_2O_3

Saturation



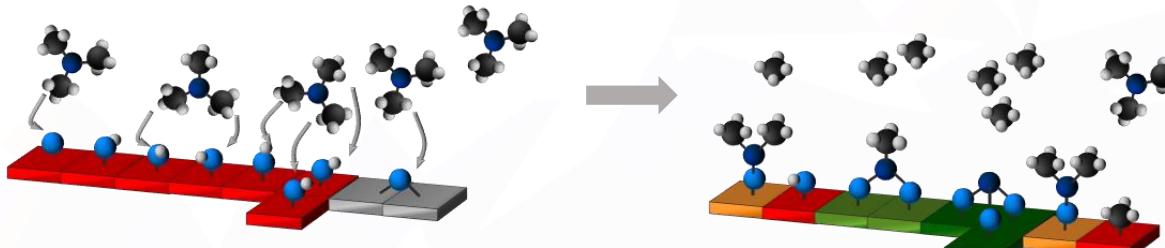
TOF- MS



ALD PROCESS

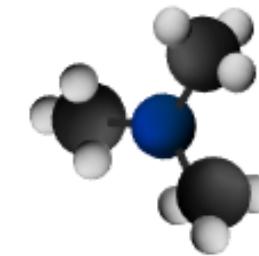
Pulse of TMA ($\text{Al}(\text{CH}_3)_3$) –in excess- and ligand exchange reaction with OH surface groups

Methane as by-product

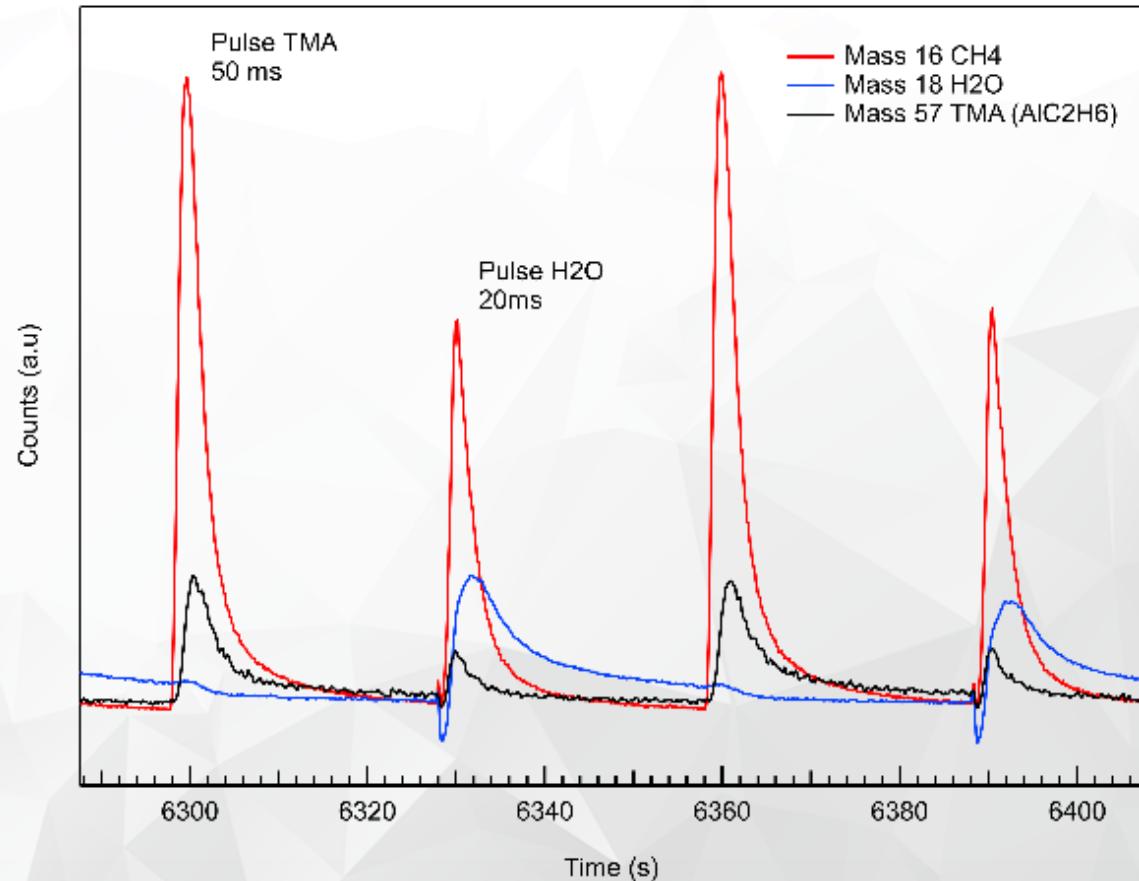


Pulse of H_2O –in excess- and ligand exchange reaction with CH_3 surface groups

Methane as by-product



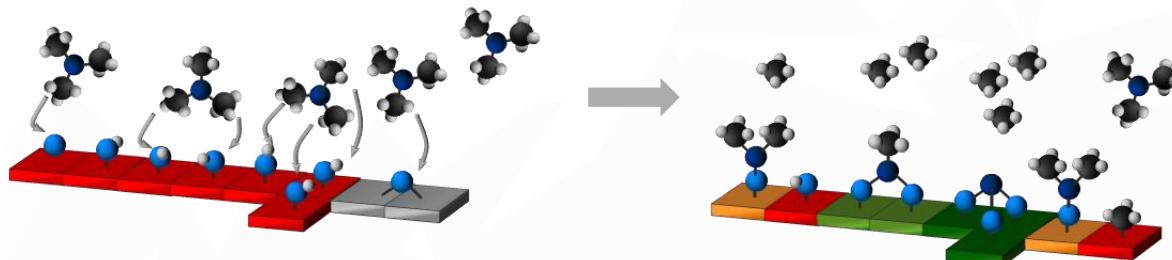
TMA – $\text{Al}(\text{CH}_3)_3$



ALD PROCESS

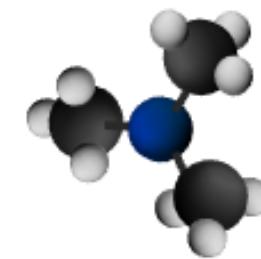
Pulse of TMA ($\text{Al}(\text{CH}_3)_3$) –in excess- and ligand exchange reaction with OH surface groups

Methane as by-product

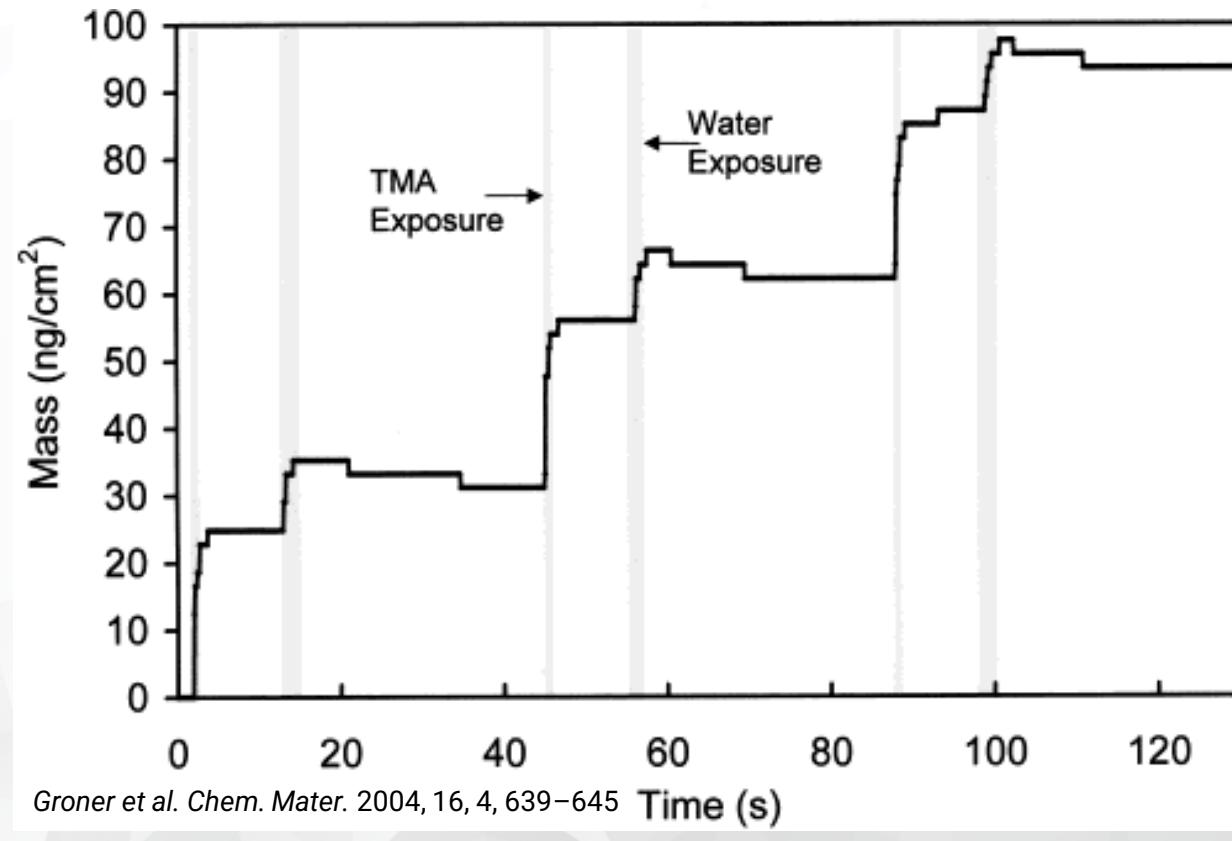


Pulse of H_2O –in excess- and ligand exchange reaction with CH_3 surface groups

Methane as by-product



TMA – $\text{Al}(\text{CH}_3)_3$

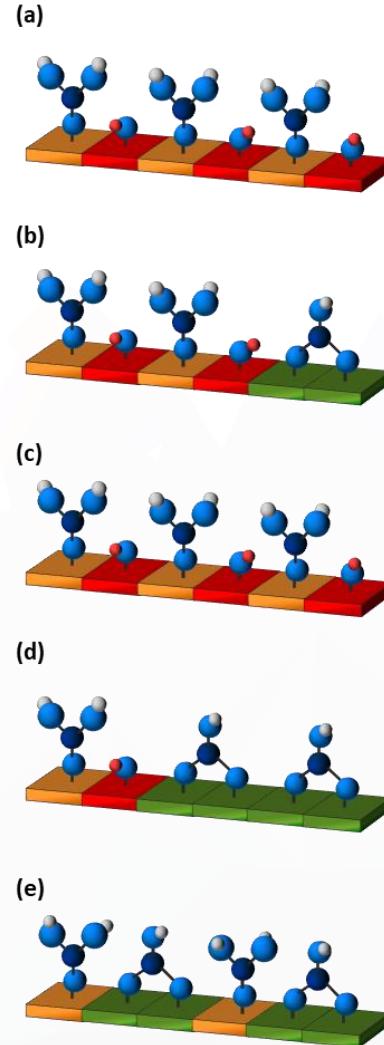


Groner et al. *Chem. Mater.* 2004, 16, 4, 639–645

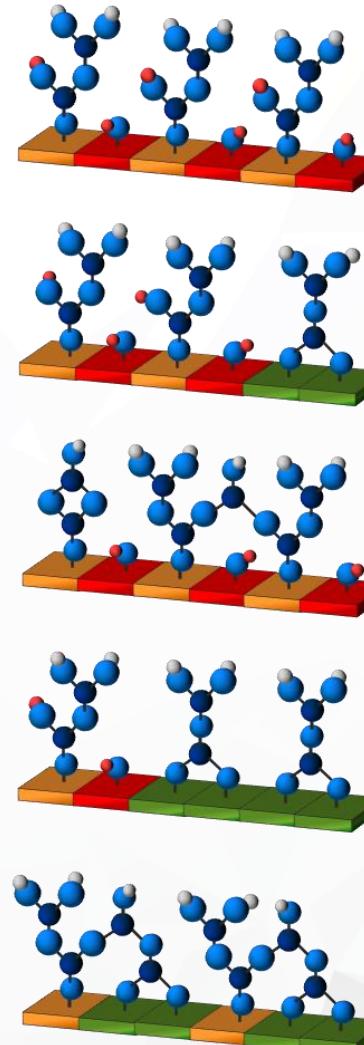
Time (s)

ALD PROCESS

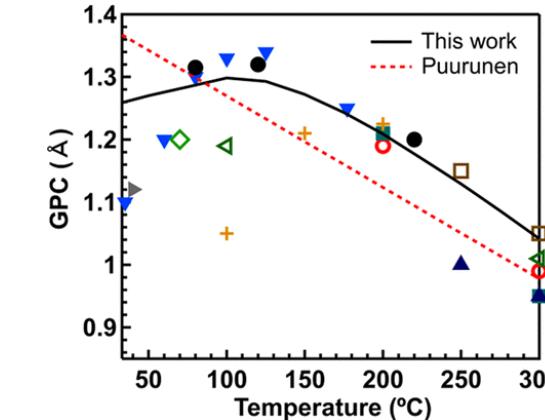
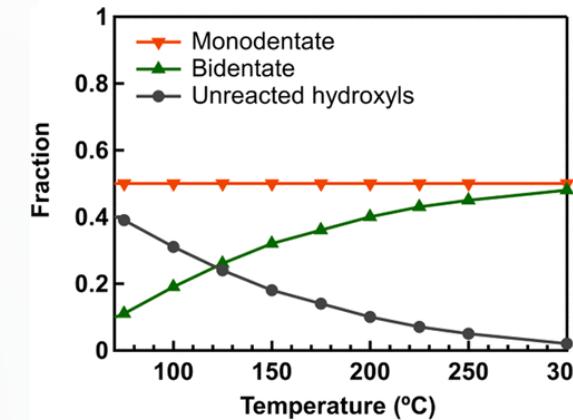
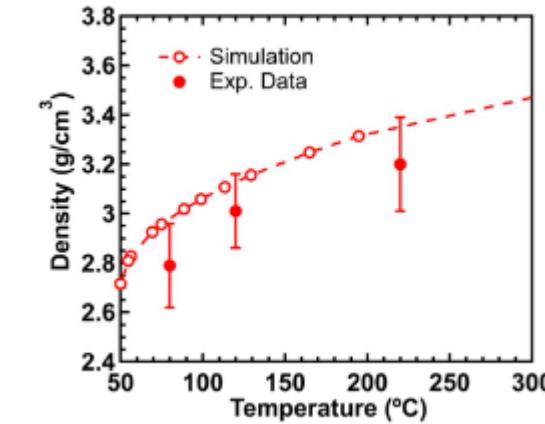
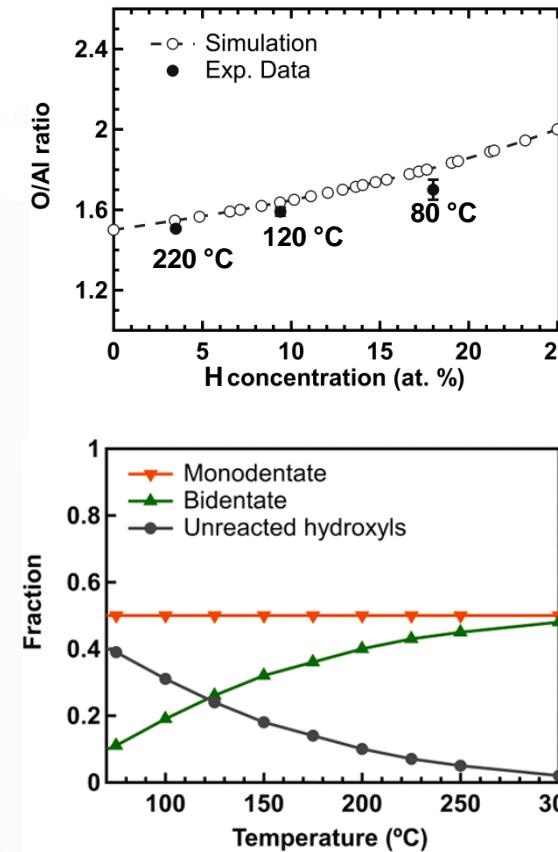
1st Monolayer



2nd Monolayer



(a) (b) (c) (d) (e)

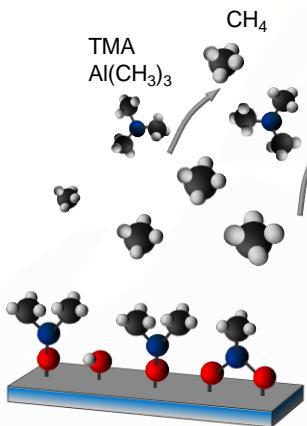


ALD PROCESS

Precursor A-Pulse

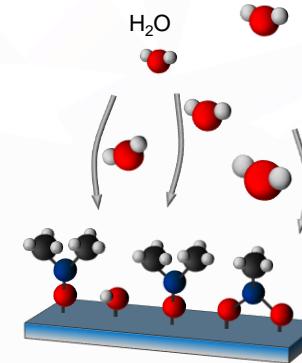


Precursor A-Purge

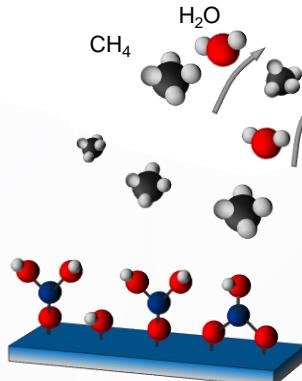


1 cycle Al_2O_3

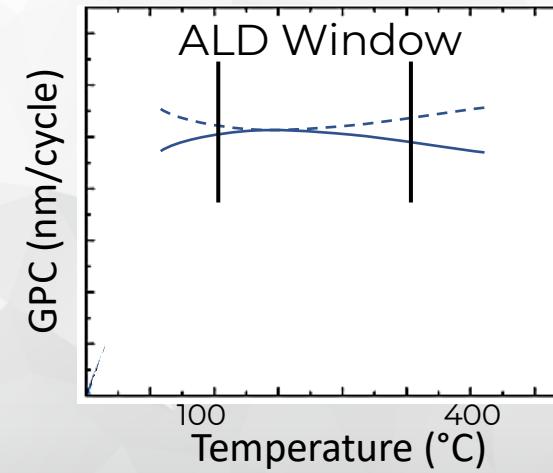
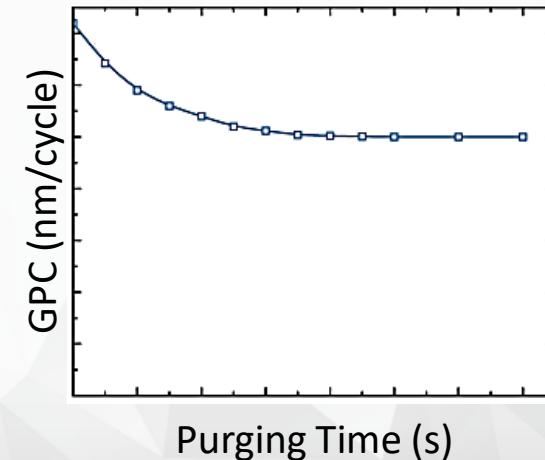
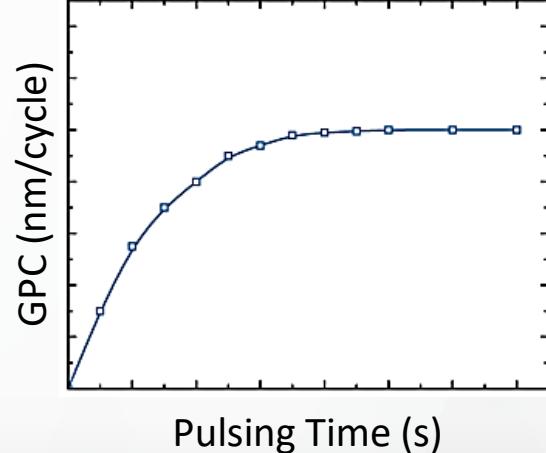
Precursor B-Pulse



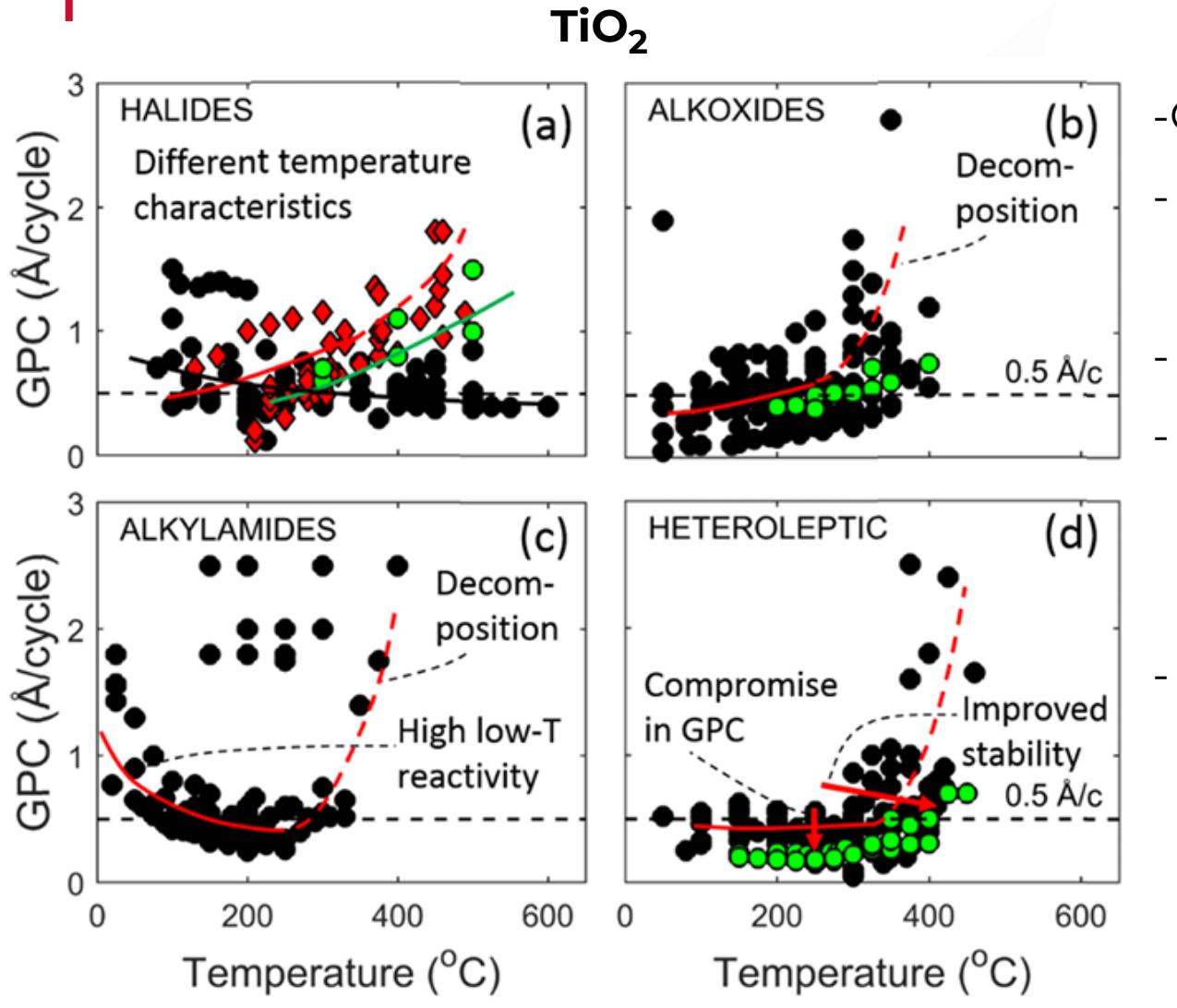
Precursor B-Purge



Saturation



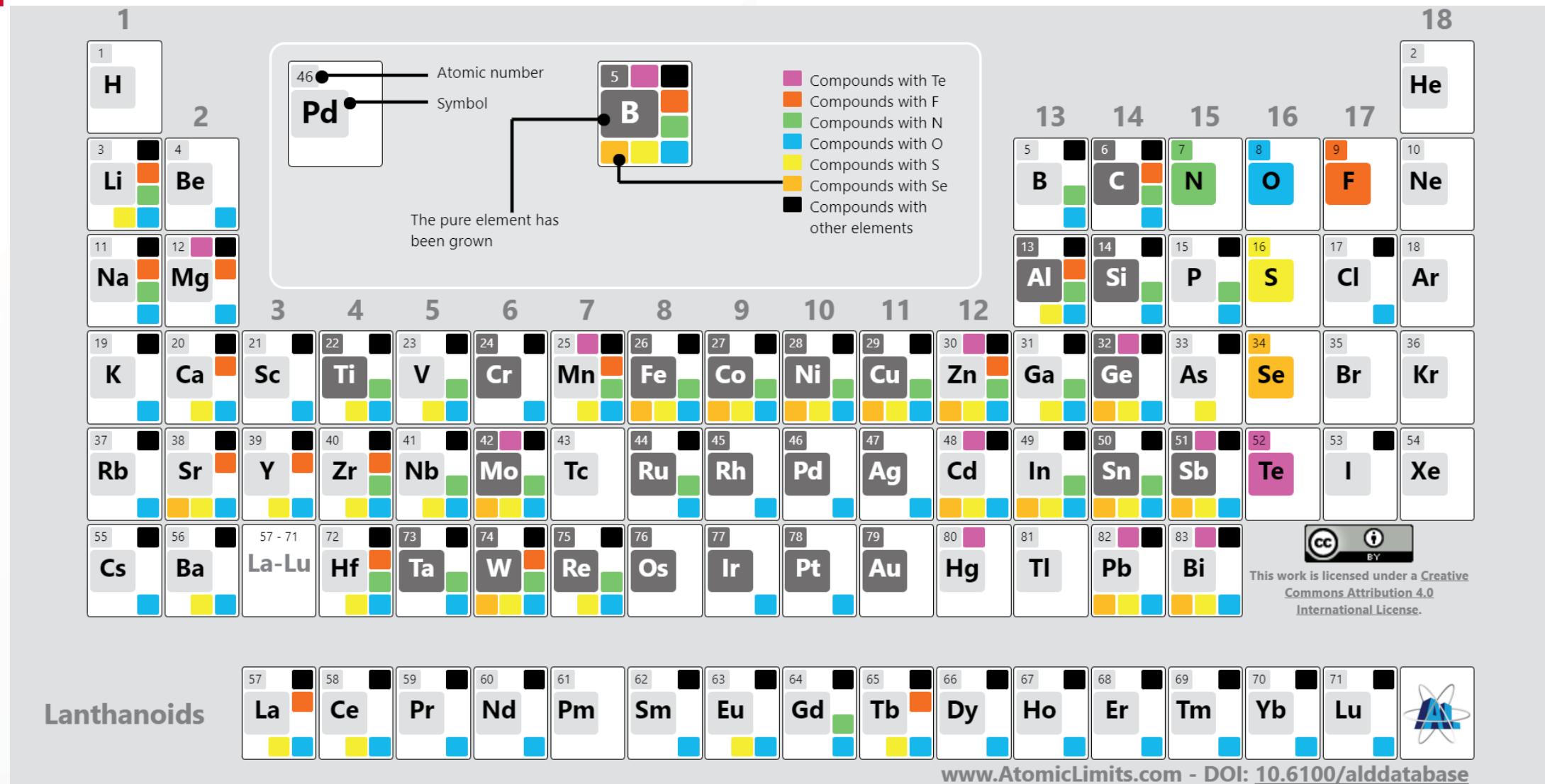
ALD PROCESS



- Chemistry of the 1st and 2nd precursor
 - Equipment (volume, Pump, pulsing position)
 - = Gas distribution and residence times
 - Homogeneity of the process
 - Process parameters (pressure, temperature)
 - (With Plasma + n variables)
- Characterization method

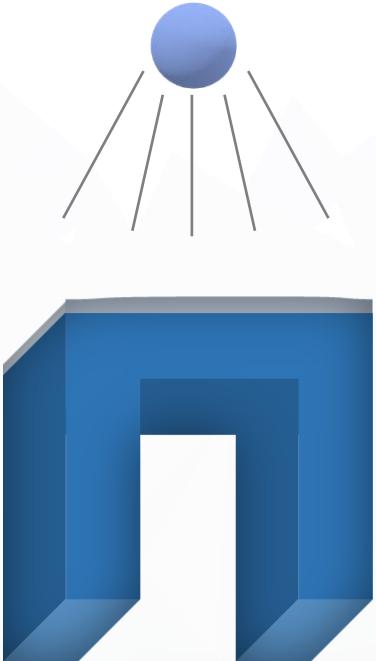
There is no perfect ALD process...
but we can try!

ALD PERIODIC TABLE

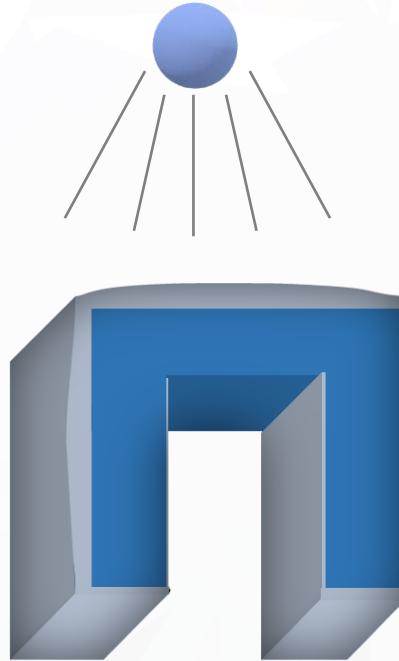


THIN FILM DEPOSITION TECHNIQUES

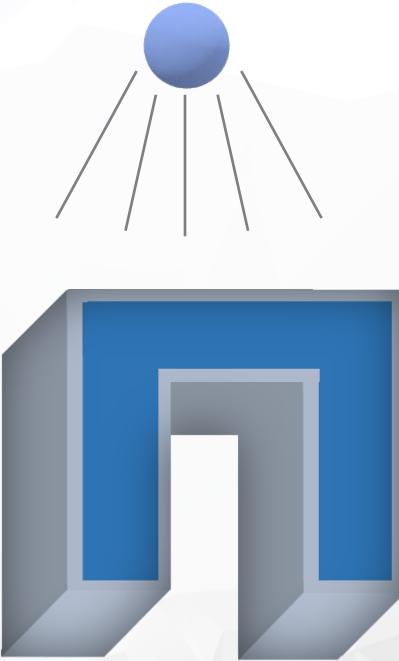
PVD



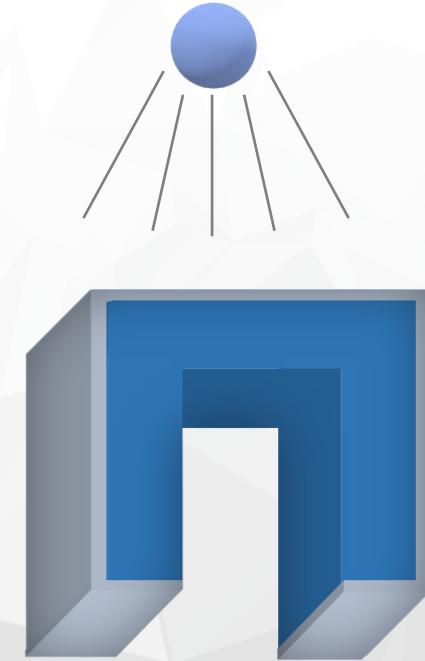
CVD



ALD

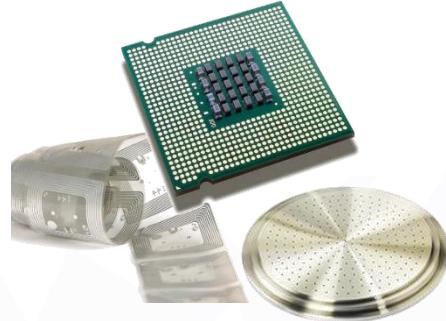


PE- ALD



ALD APPLICATIONS

Semiconductor



Medical Equipment



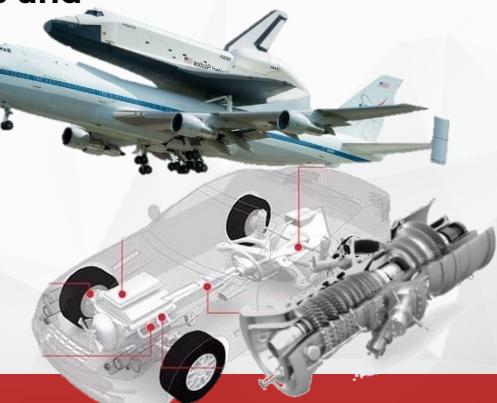
Consumer Electronics



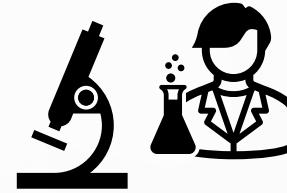
Optics



Automotive and Aerospace



R & D



Decorative Parts



**Barrier/protection
Passivation
Adhesion
Sacrificial
Anti-reflection
- corrosion**

...

**TCO
Interference colors
Bio-compatible**

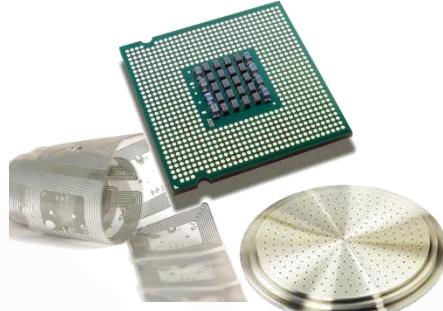
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Energy Generation and Storage

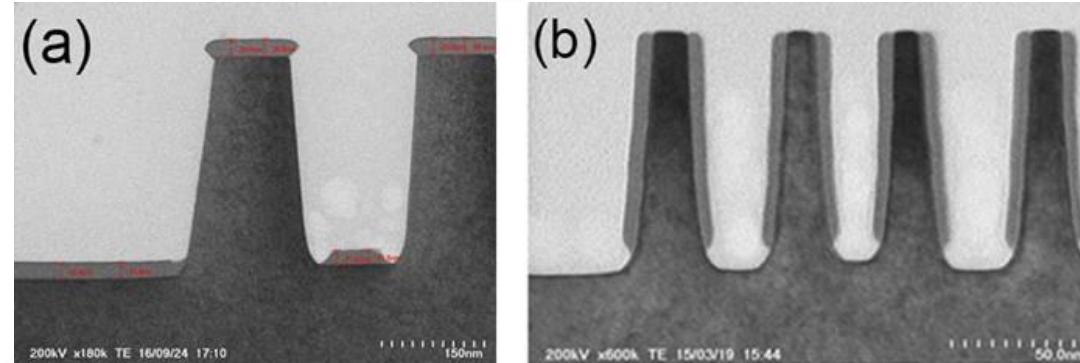


ALD APPLICATIONS

Semiconductor

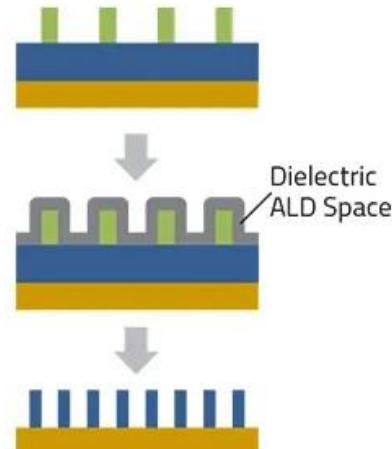


PE-ALD SiN on 3D NAND

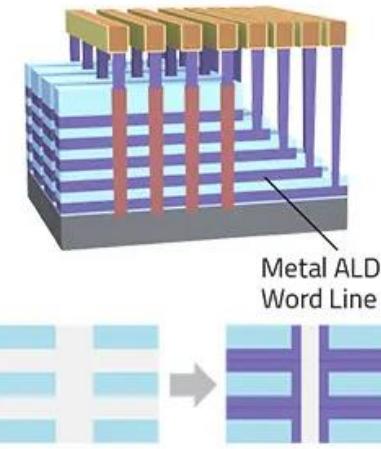


Harm C. M. Knoops, et al. Journal of Vacuum Science & Technology A 37, 030902 (2019)

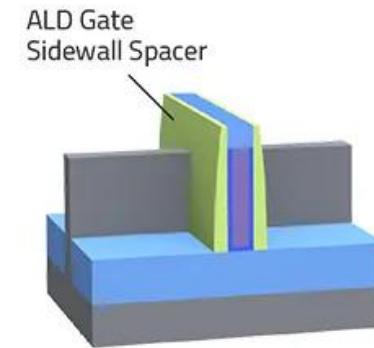
Multiple Patterning



3D NAND



FinFET



Lam Research



ALD APPLICATIONS

Medical Equipment



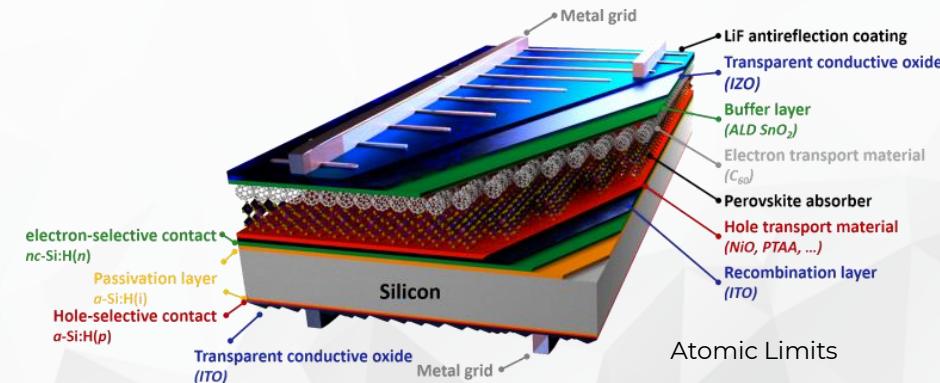
Positive Coating

Decorative Parts



Positive Coating

Energy Generation and Storage

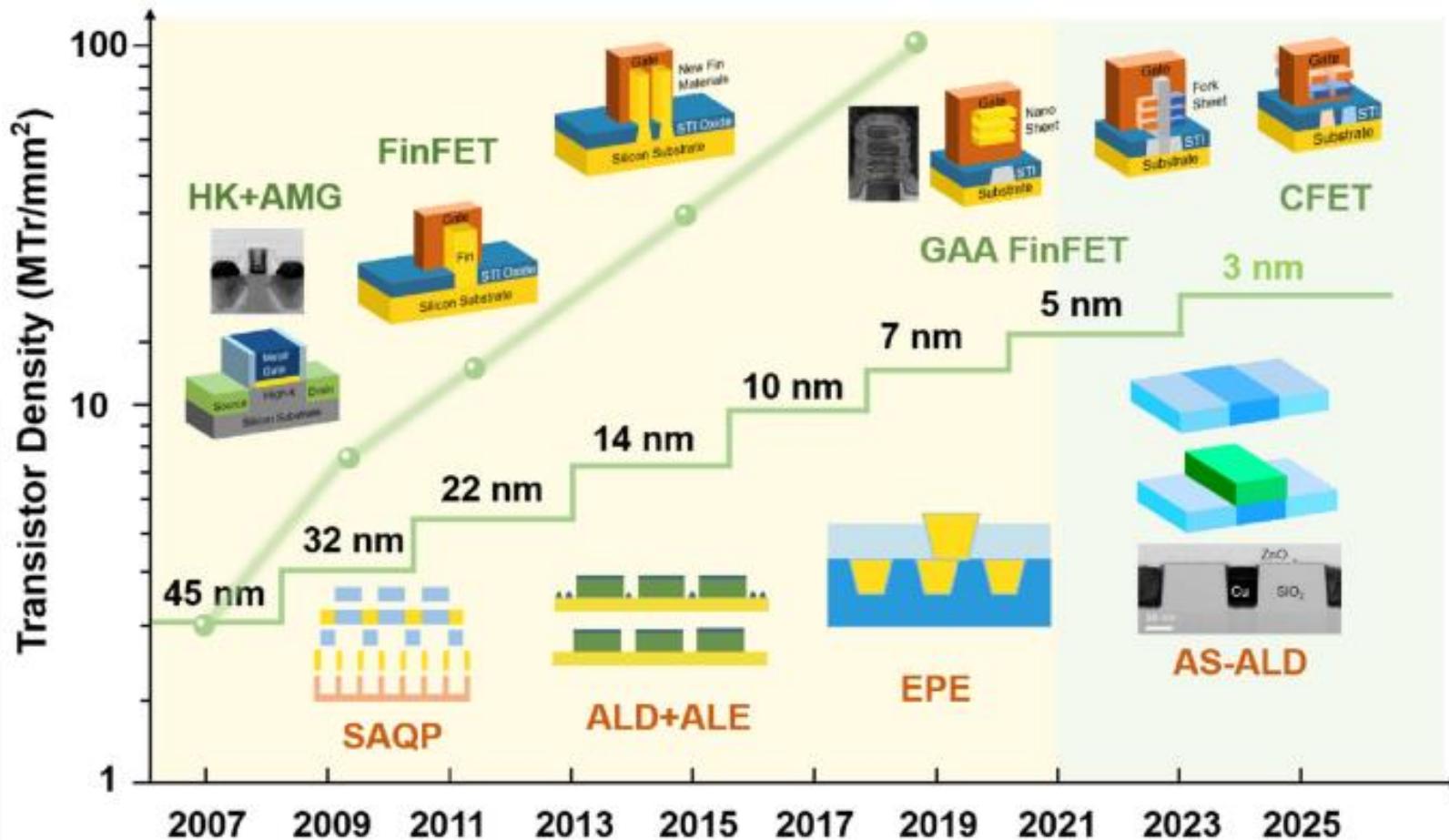


Atomic Limits

WHY ALD AND PVD

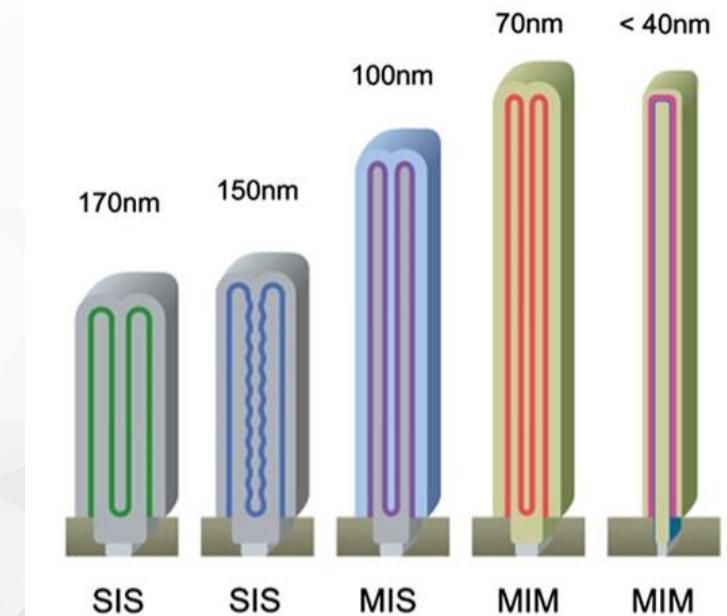
ALD / PVD FOR MICROFABRICATION

Semiconductor



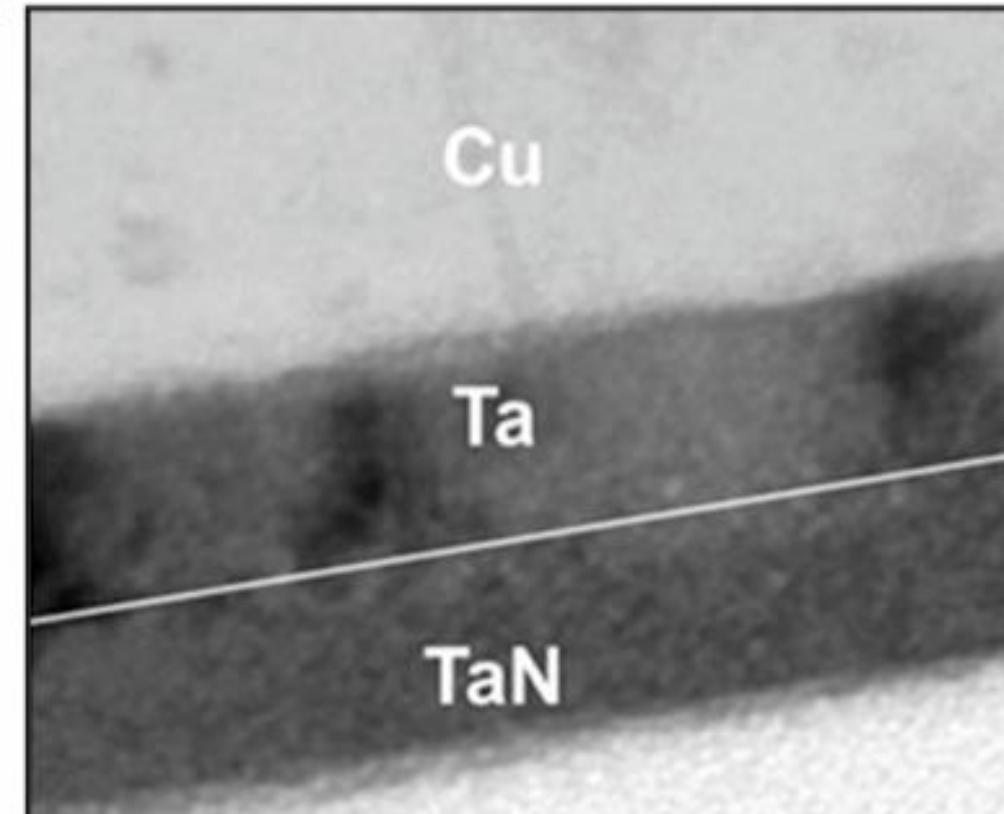
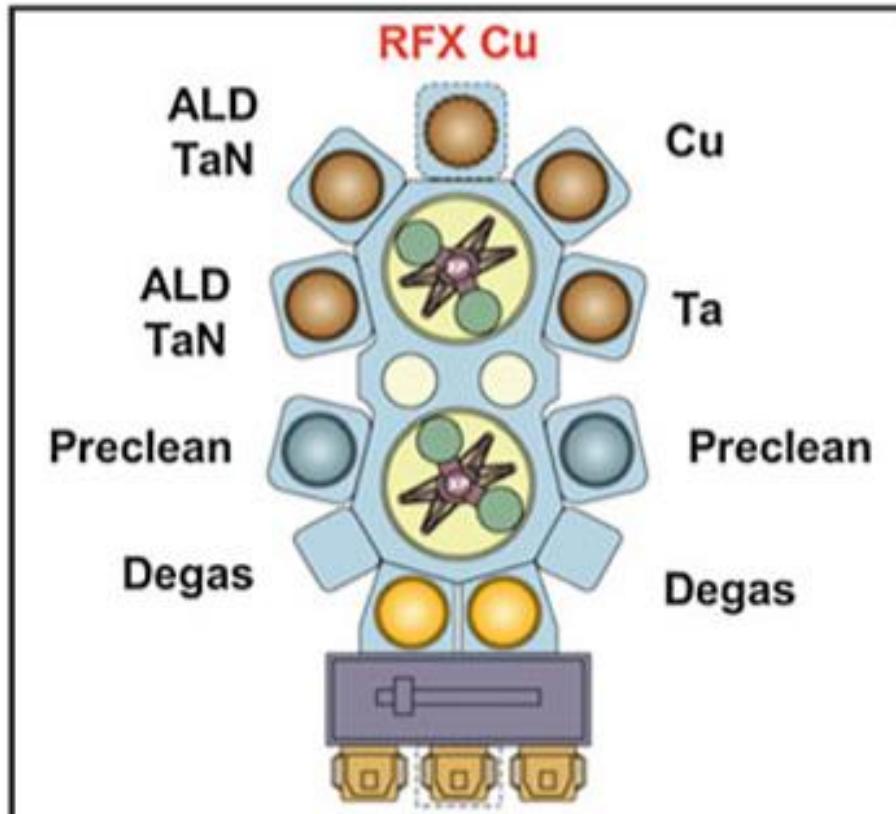
Zhang, J., Li, Y., Cao, K. et al. Advances in Atomic Layer Deposition. *Nanomanuf Metrol* 5,

C. S. Hwang et al.



ALD / PVD FOR MICROFABRICATION

Semiconductor



C. S. Hwang et al.

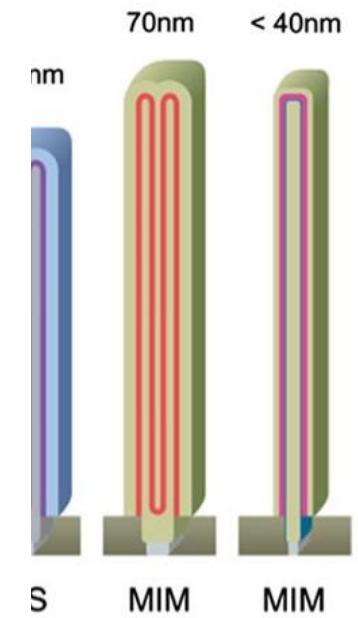
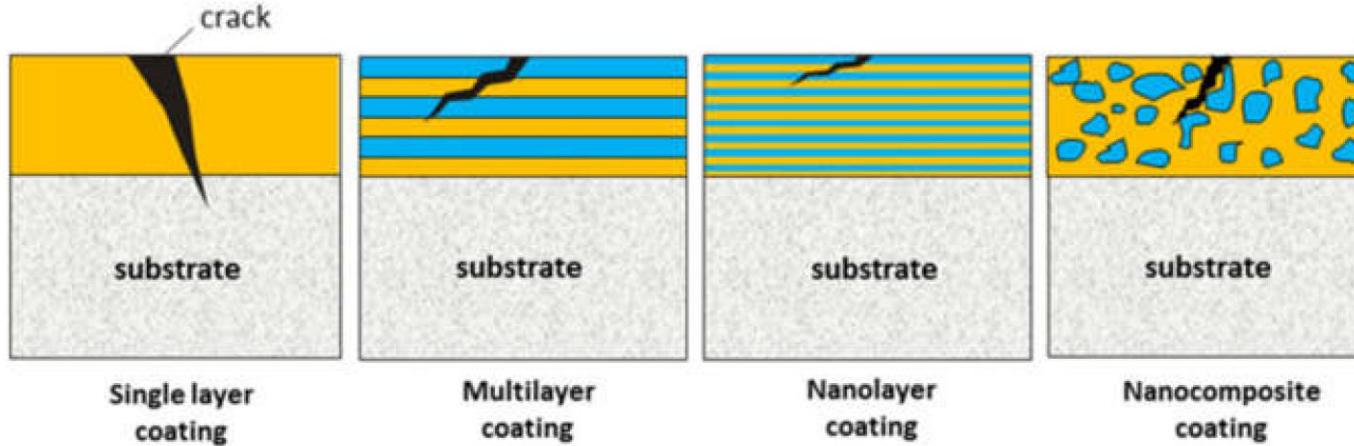


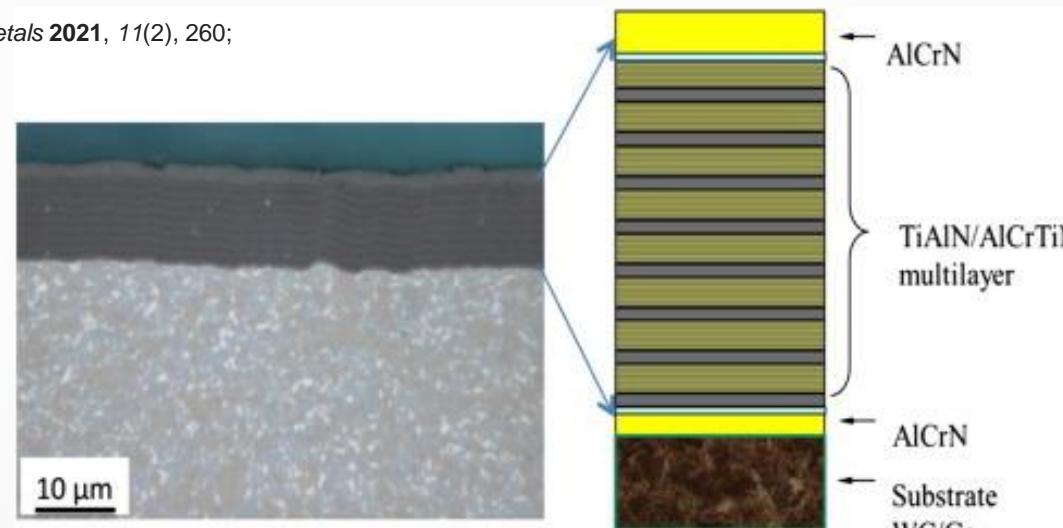
Fig. 9.2 Integrated barrier-seed system with ALD TaN chambers (Courtesy of applied materials)

ALD / PVD FOR THIN FILM ENGINEERING

Harder and Stronger Coatings

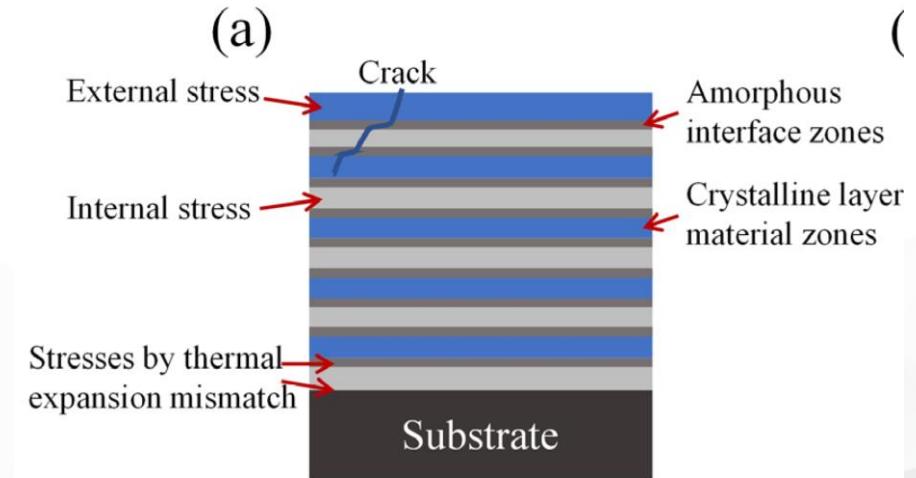


Sousa et al. *Metals* 2021, 11(2), 260;

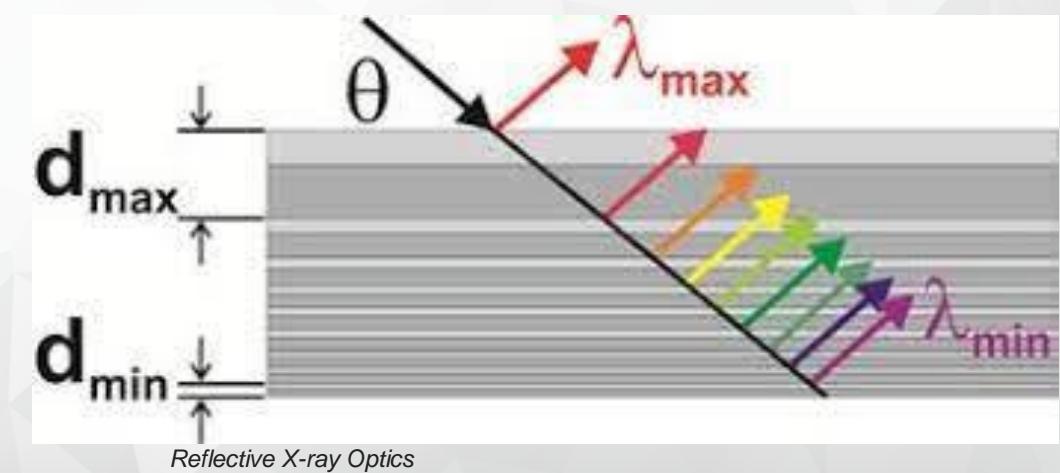


Aharon Inspektor, Paul A. Salvador, *Surface and Coatings Technology*, Volume 257, 2014

Tailored Optical Properties

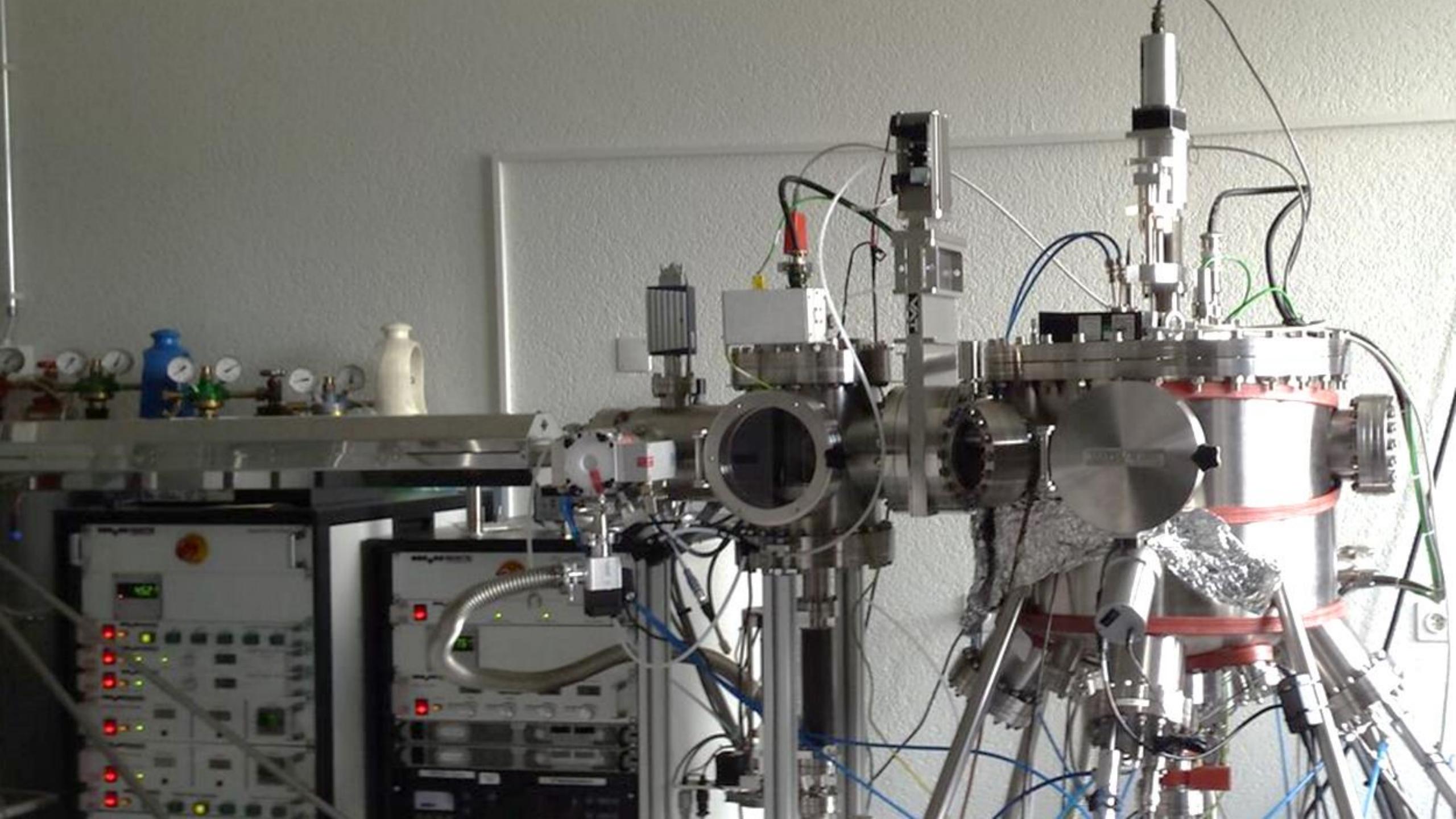


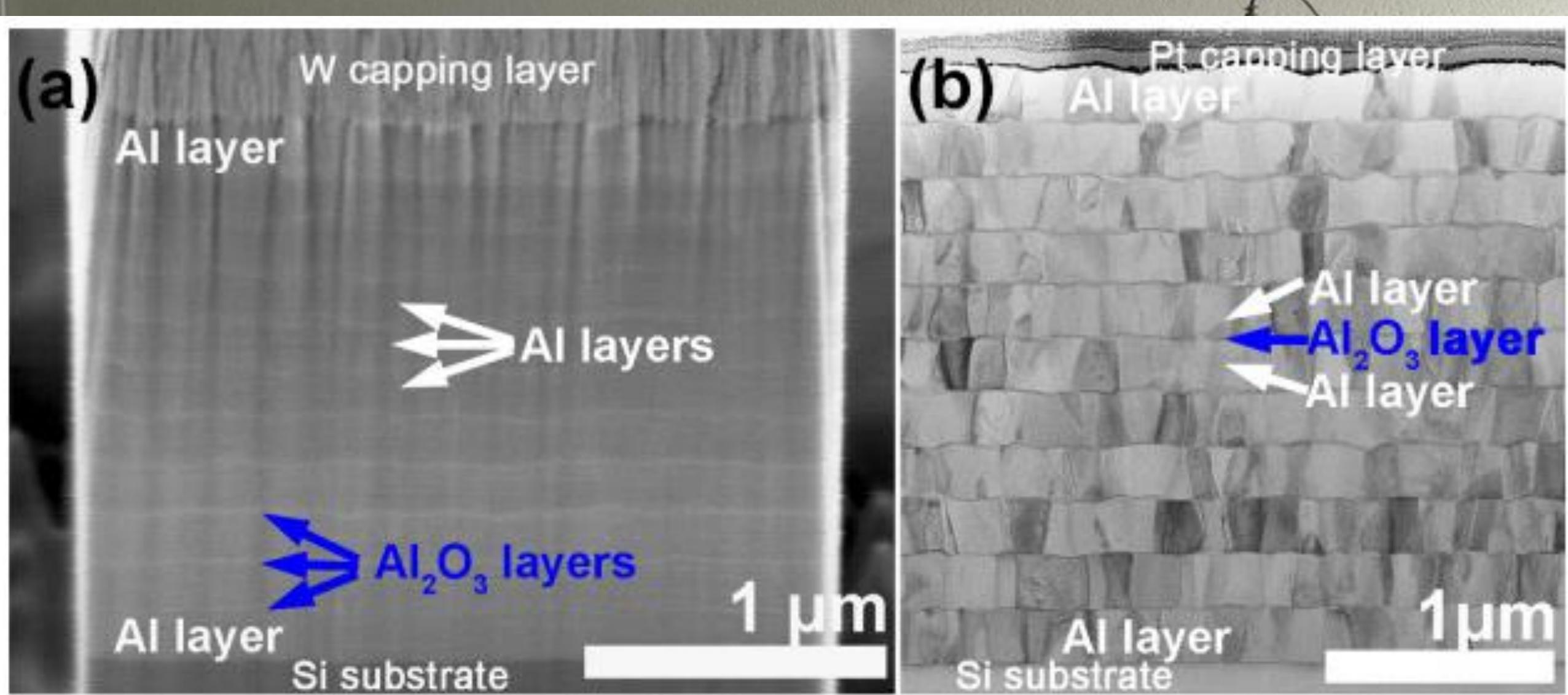
Holleck, Lahres and Woll. *Surface and Coatings Technology*, 1990



HOW TO COMBINE ALD WITH PVD

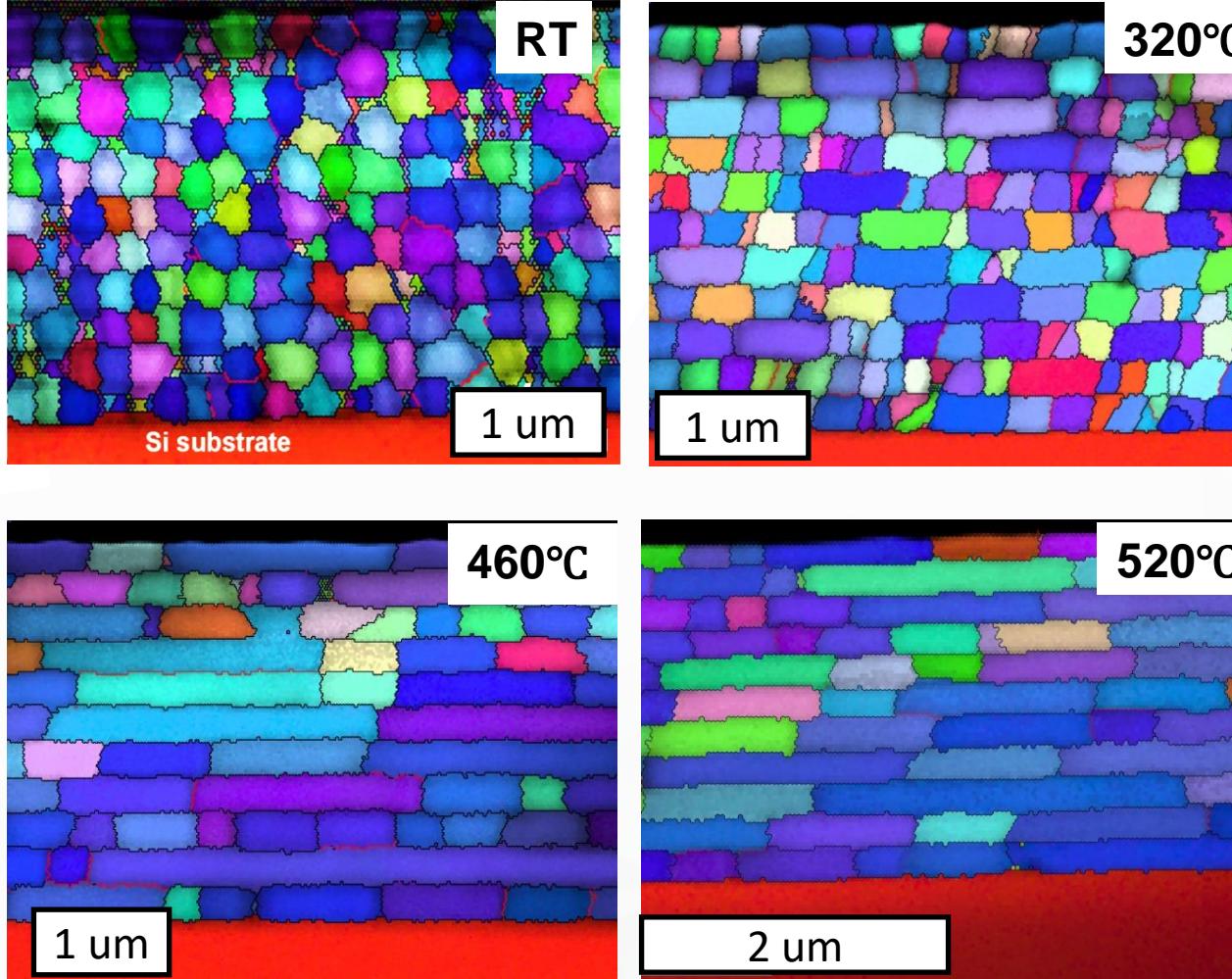




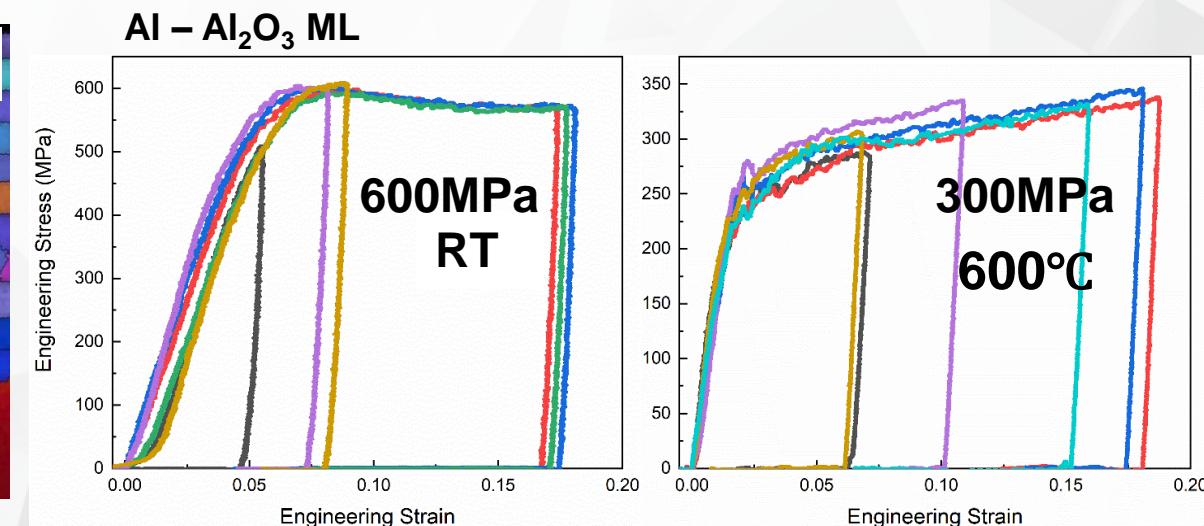
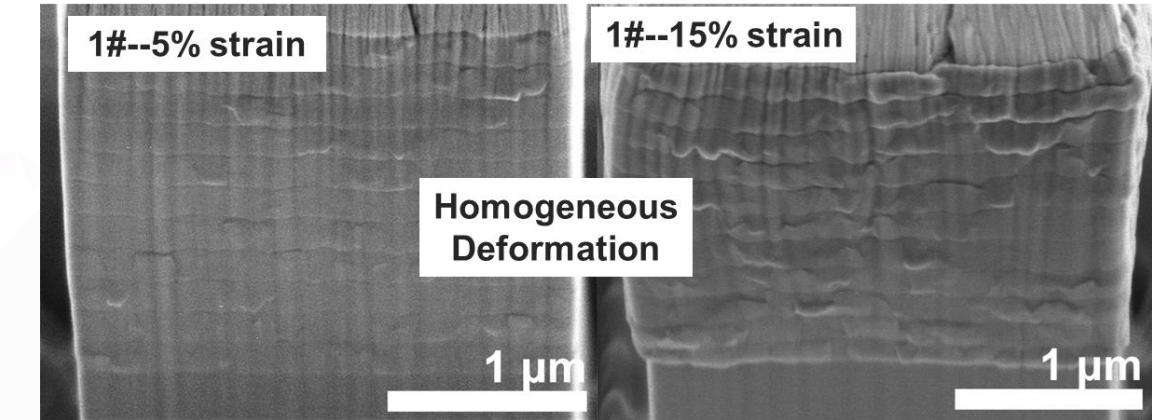


ALD-PVD COATINGS

10x (PVD Al 250 nm – ALD Al_2O_3 1 nm)

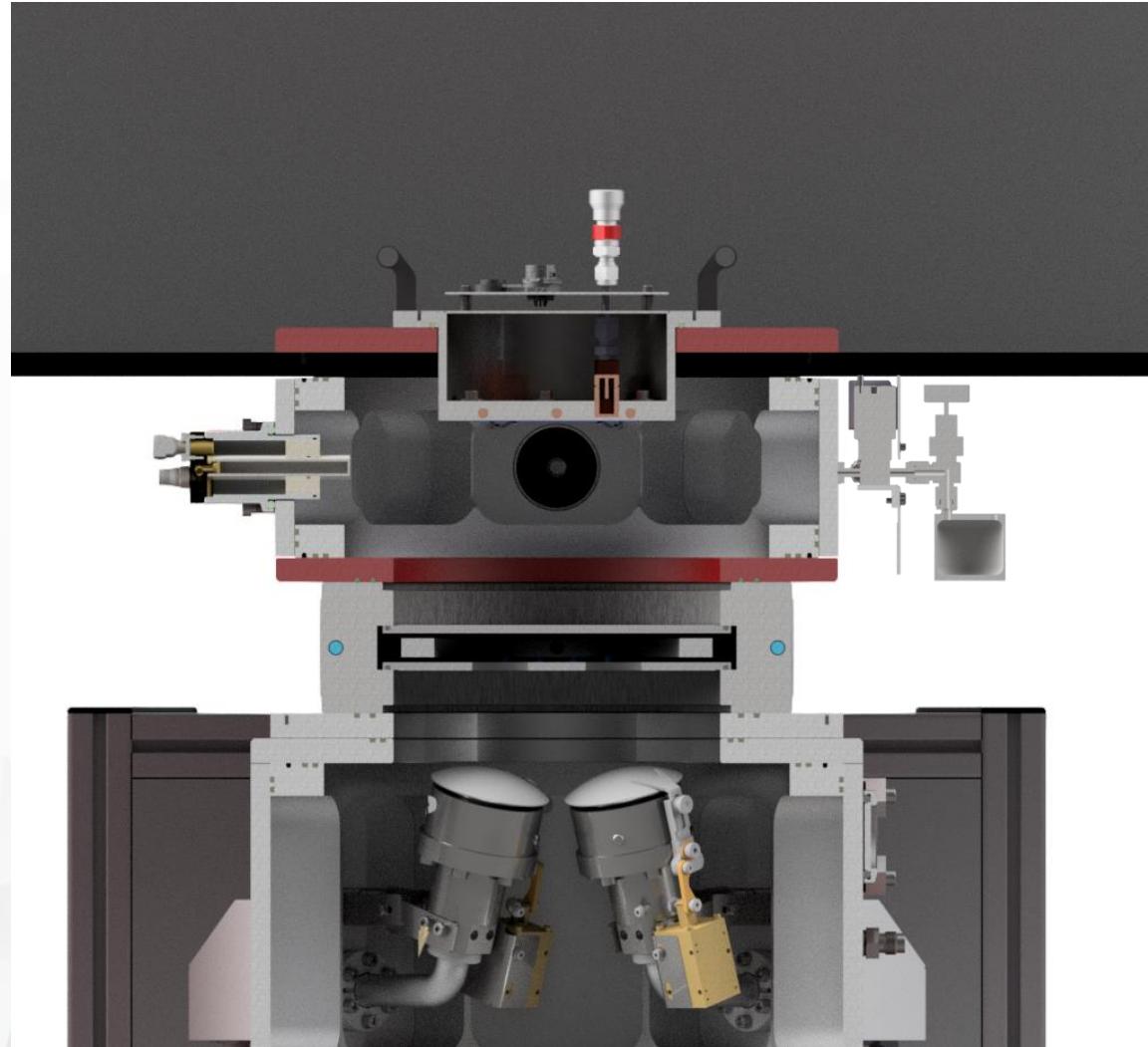
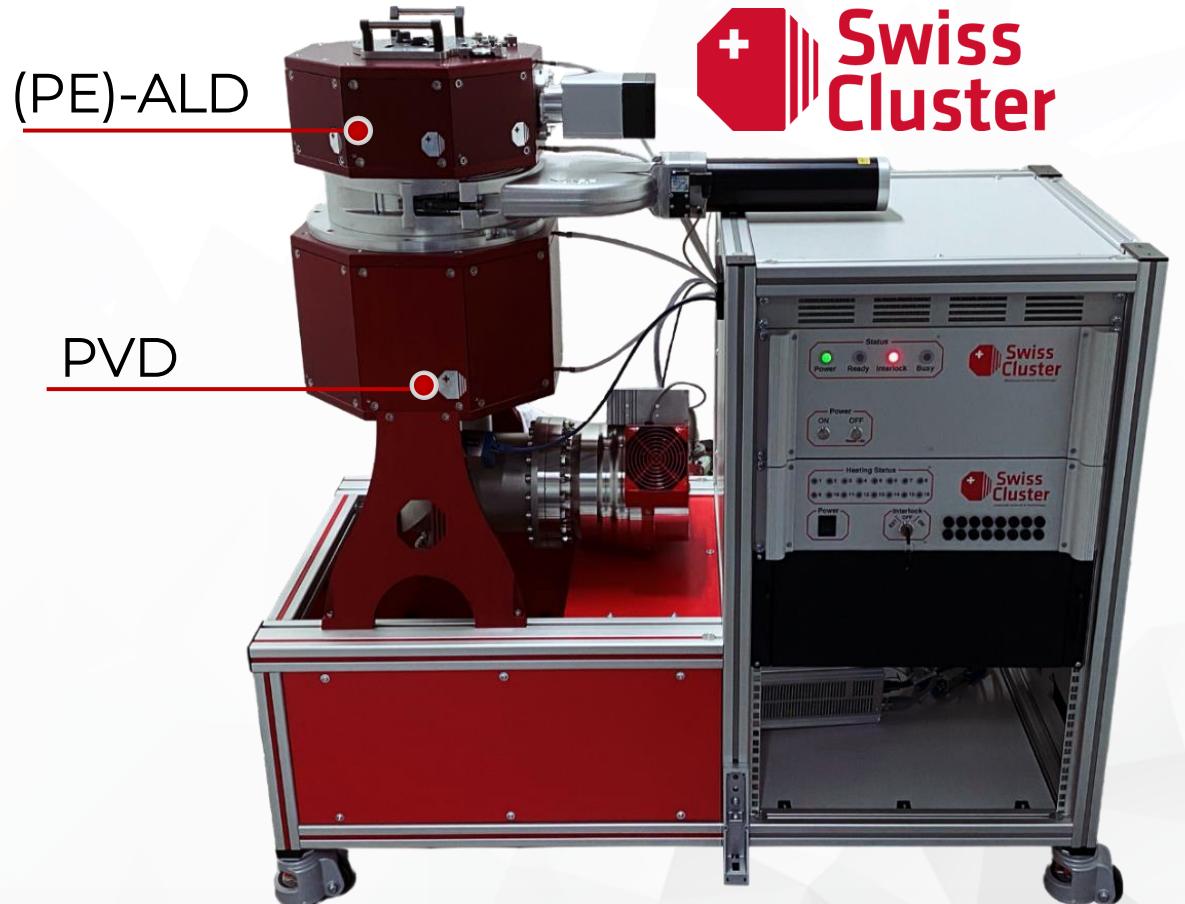


Pure Al: 300 – 400 MPa
Al alloys: ~600- 700 MPa



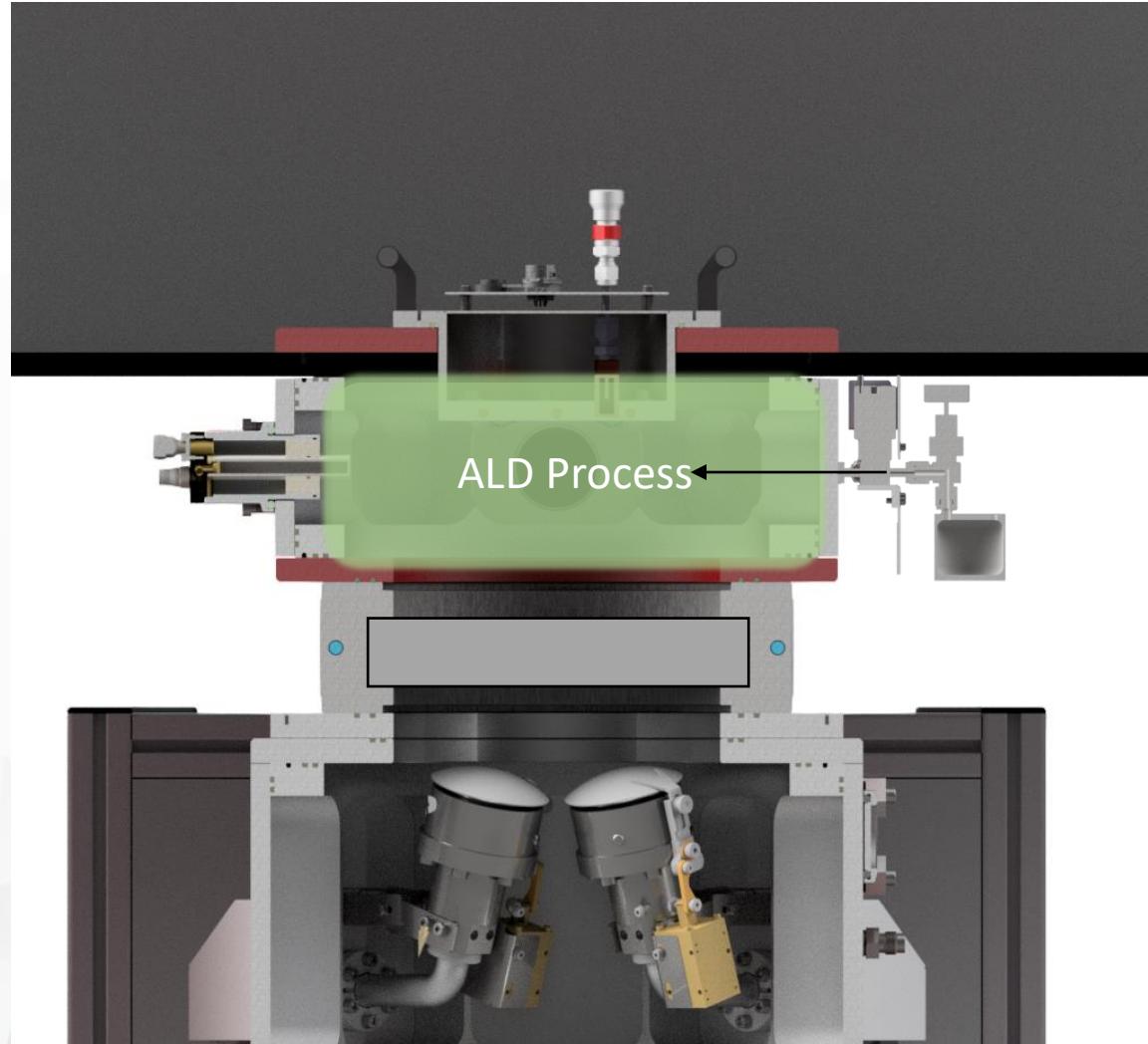
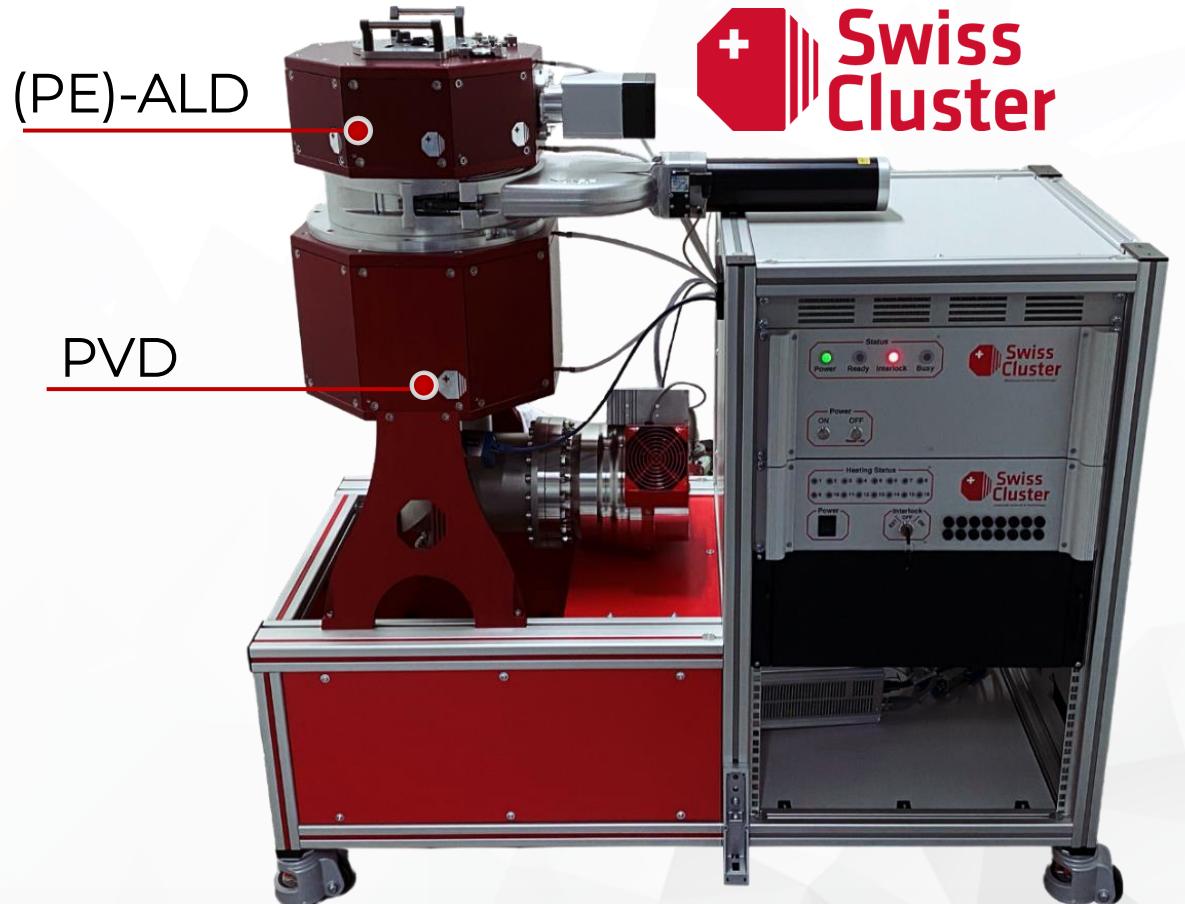
SWISS CLUSTER EQUIPMENT

The SC-1



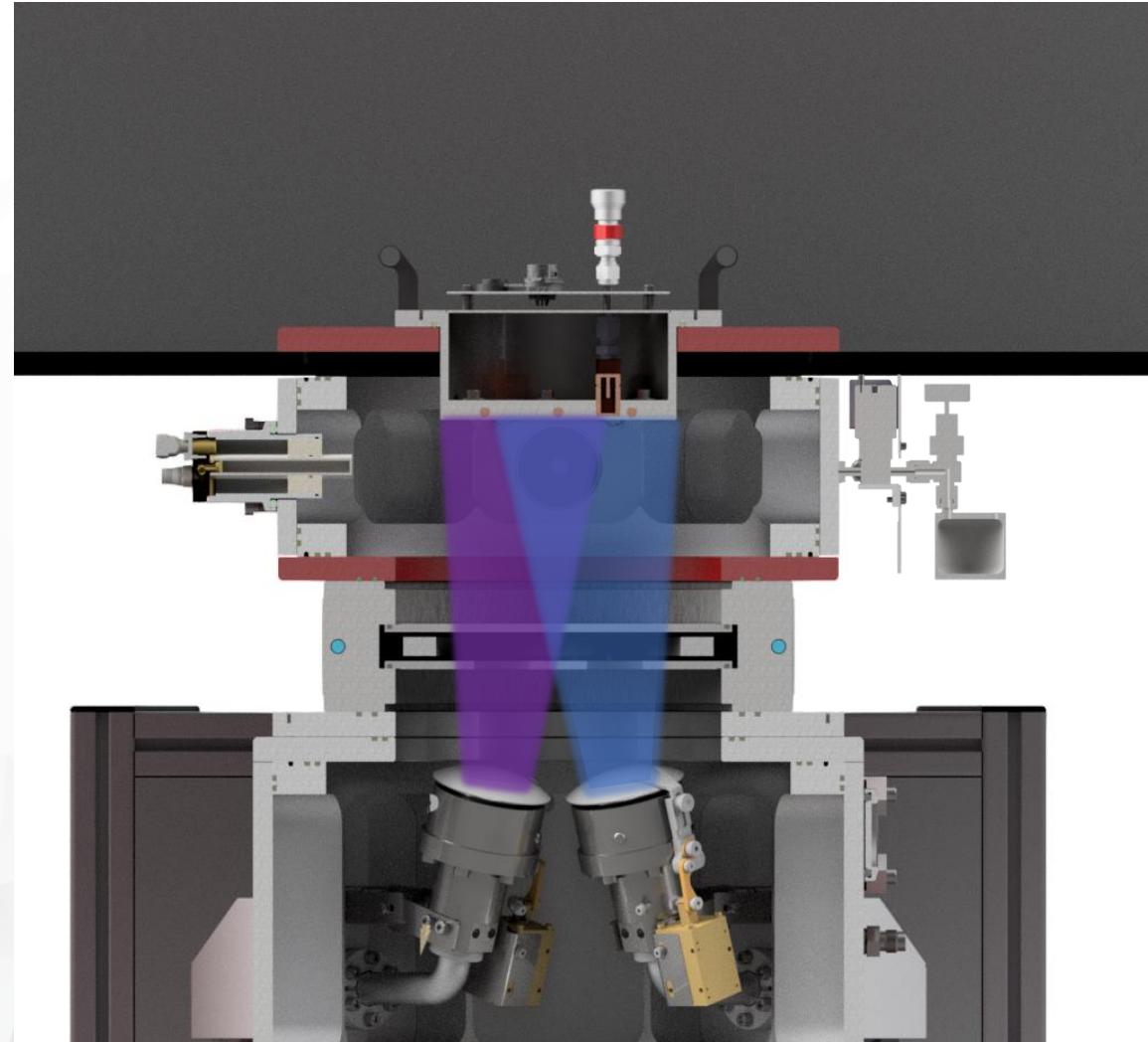
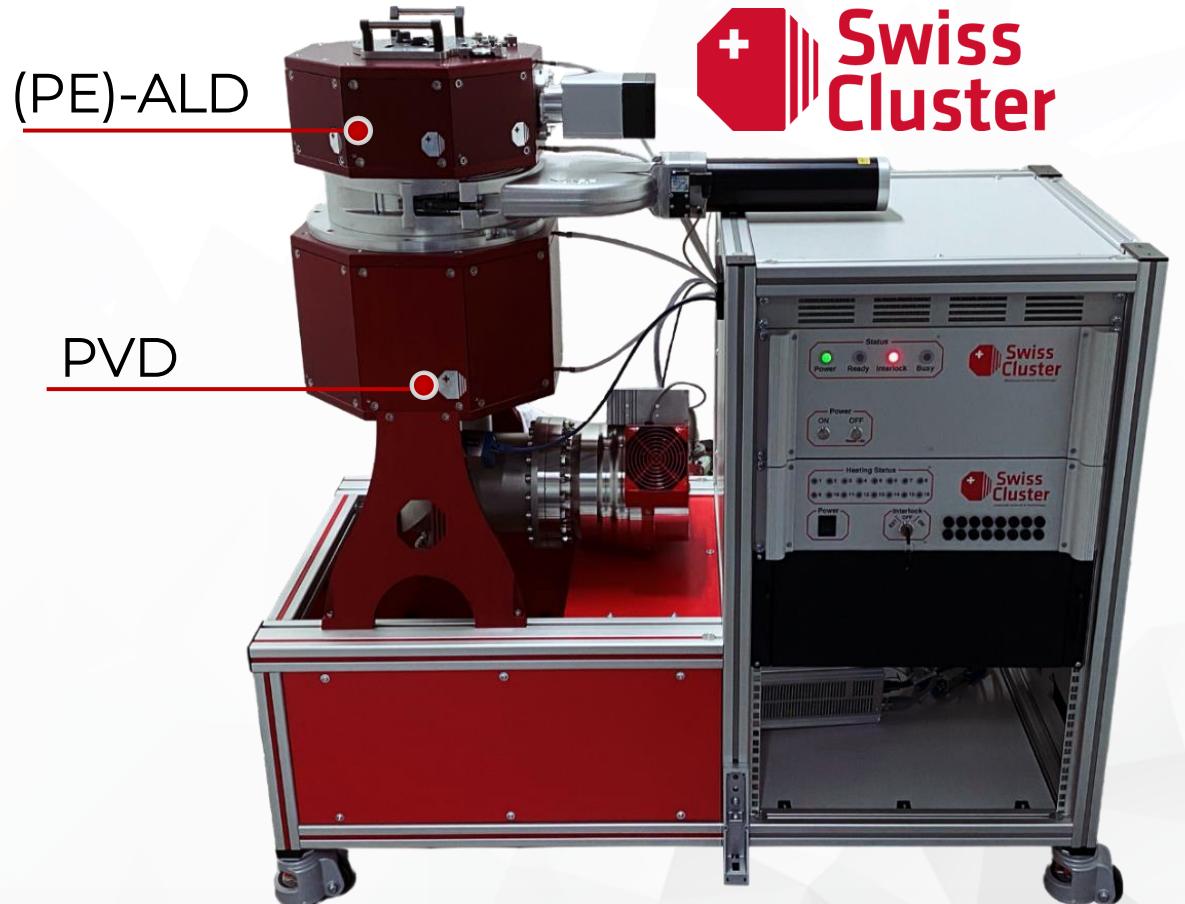
SWISS CLUSTER EQUIPMENT

The SC-1



SWISS CLUSTER EQUIPMENT

The SC-1



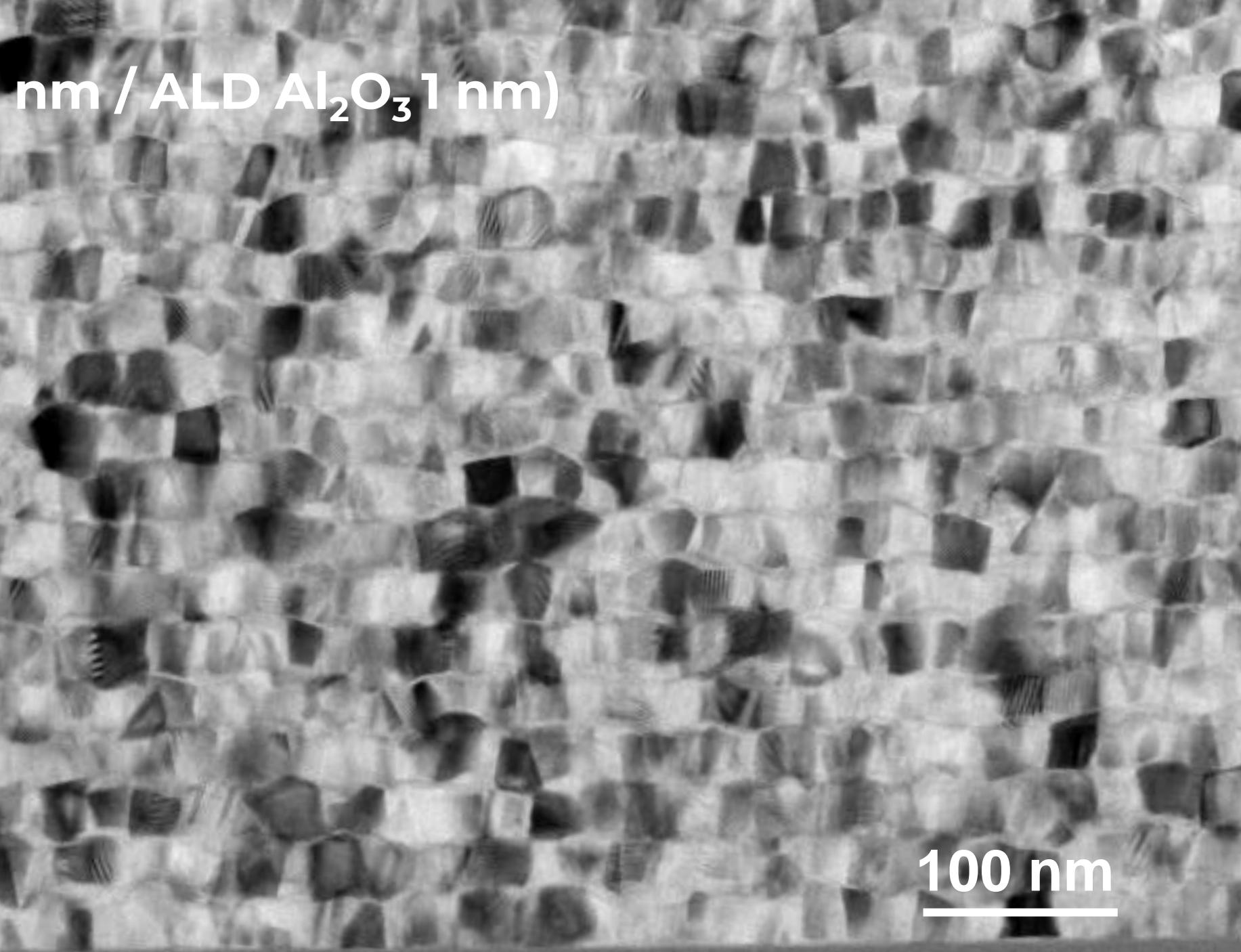
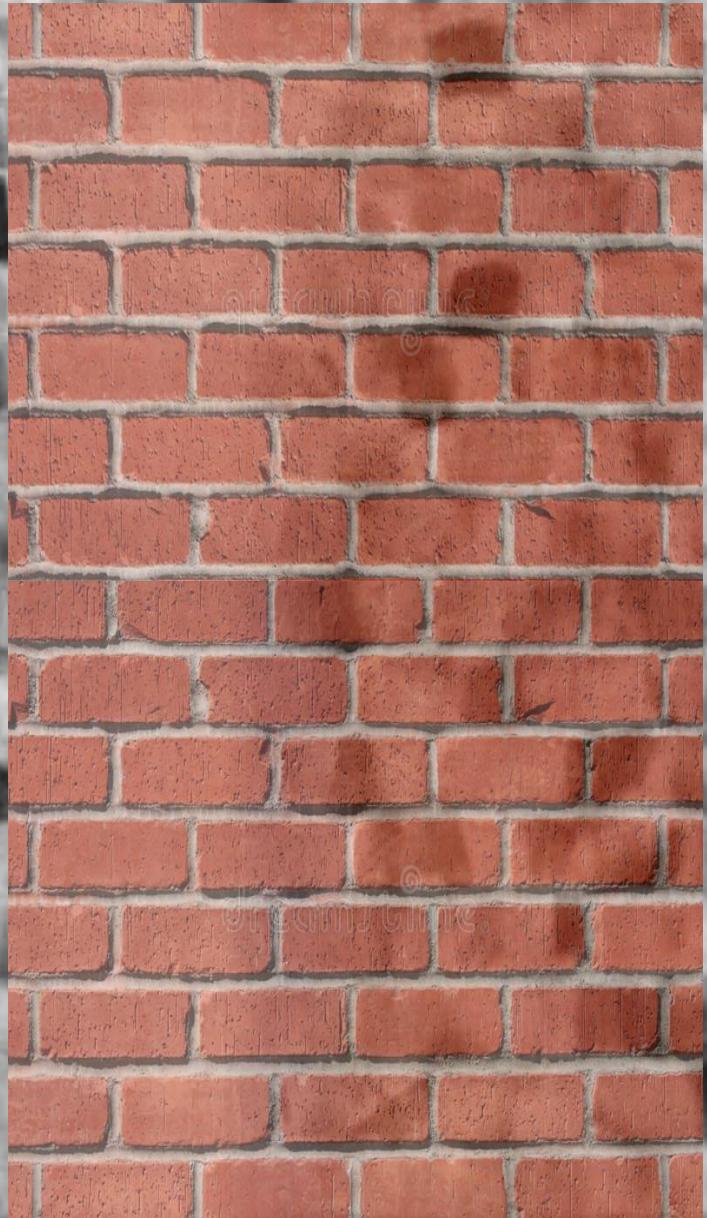
100x (PVD Al 20 nm / ALD Al_2O_3 1 nm)

2 um

100x (PVD Al 20 nm / ALD Al_2O_3 1 nm)

500 nm

100x (PVD Al 20 nm / ALD Al_2O_3 1 nm)



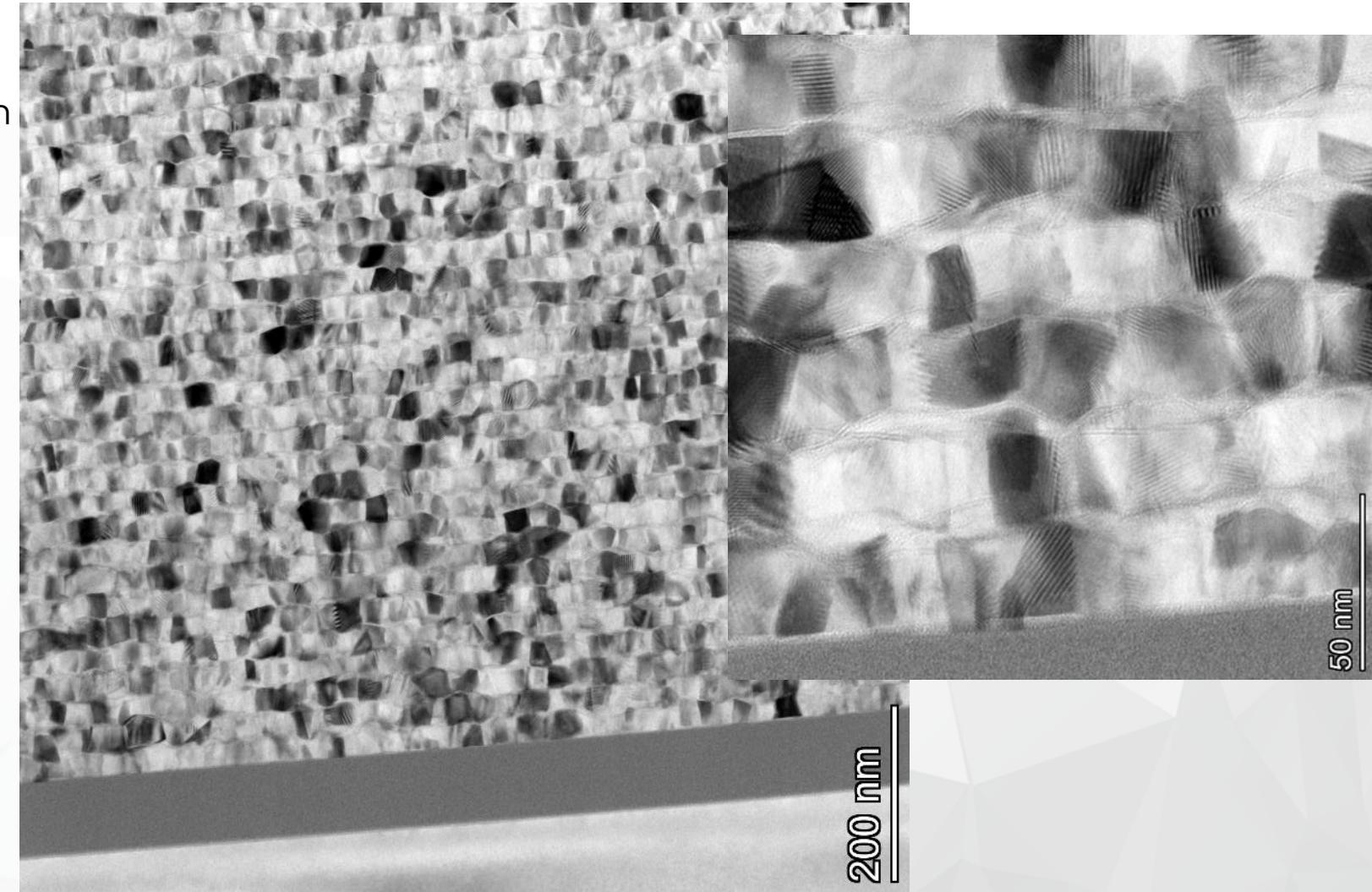
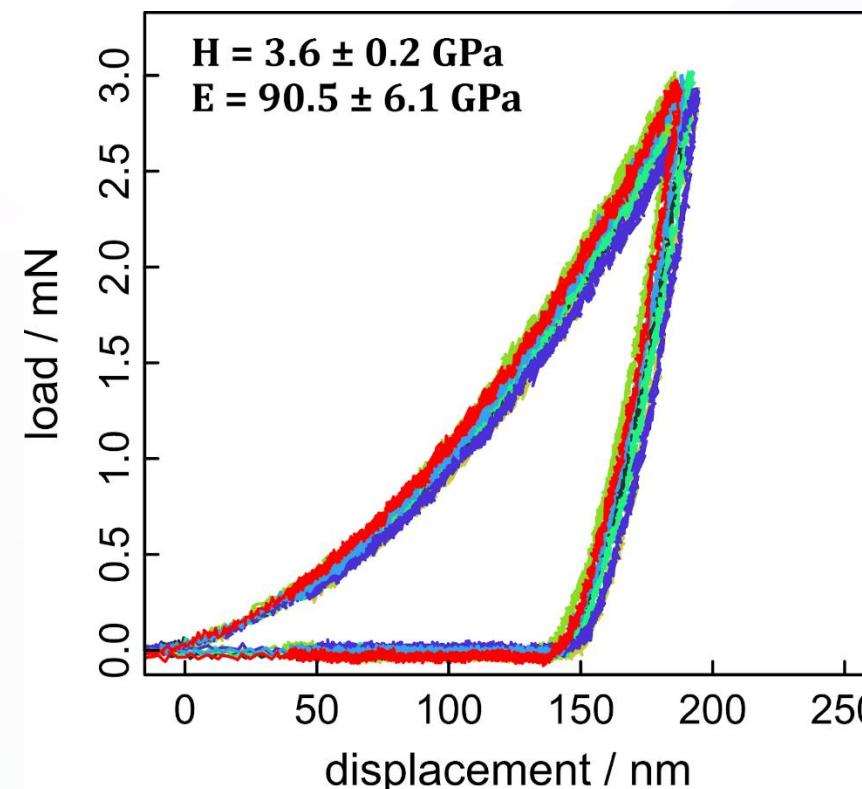
100 nm

PVD-ALD RESULTS

100x (PVD Al 20 nm – ALD Al_2O_3 1 nm)

Improving hardness and yield strength

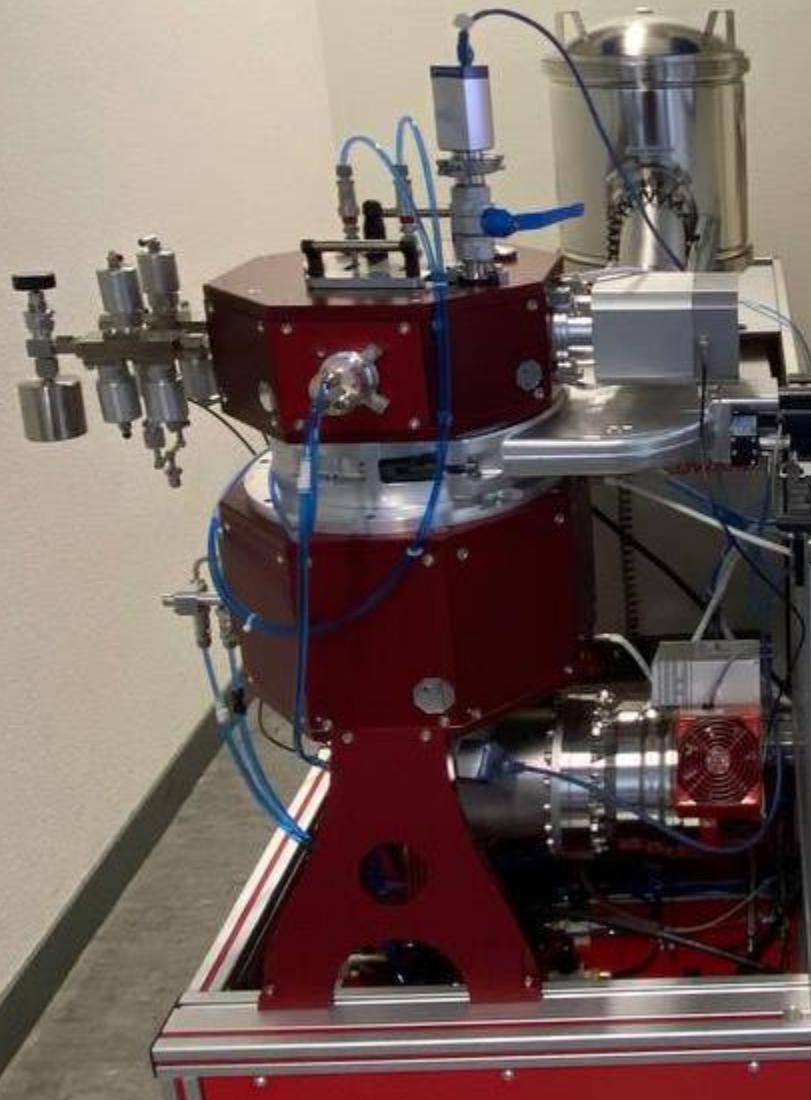
3.6 Gpa in Hardness
~1.2 Gpa in Yield strength



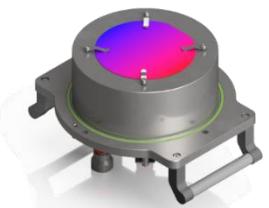
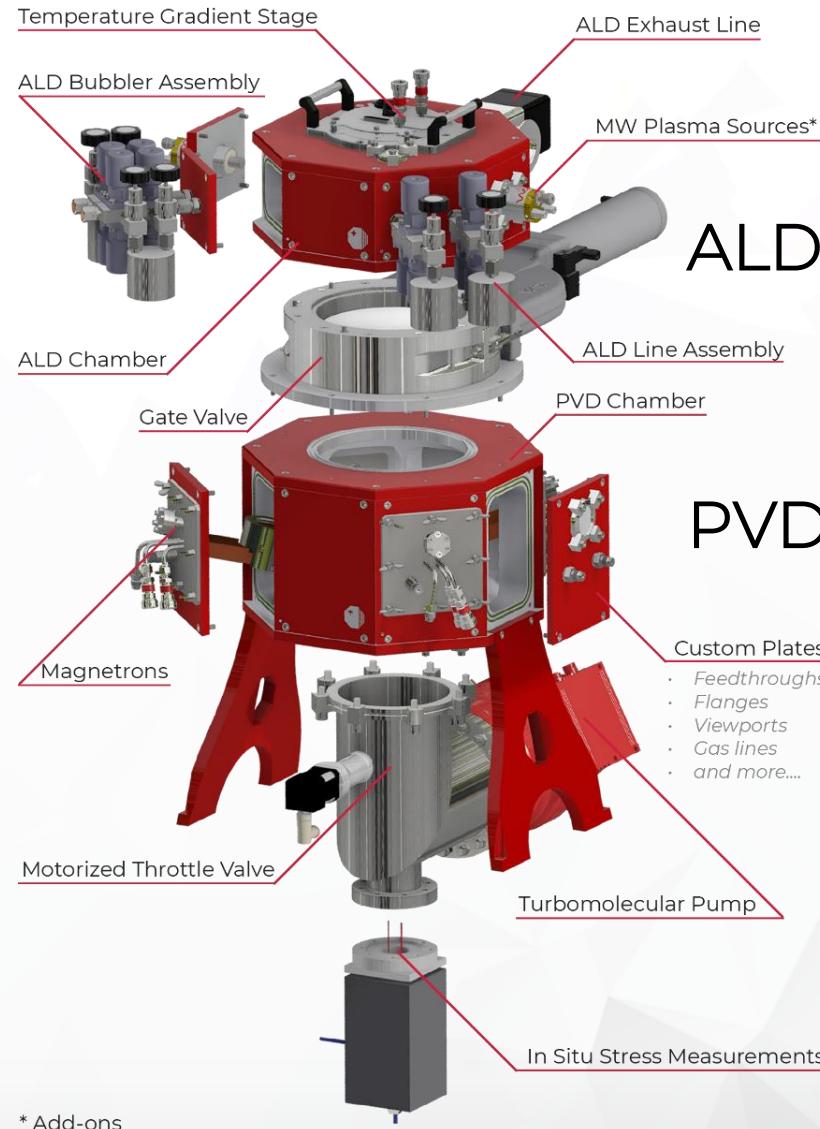
 Swiss
Cluster

Science, Business & Technology

Innovate, Inspire, Breakthrough



R & D EQUIPMENT & COMPONENTS



Customized stage holders (4 – 8 in.)

- Temperature gradient stage (450°C – 30 °C)
- High Temperature
- Rotational and z-stage



MW Plasma sources

- PE-ALD and MARS



HiPIMS Compatible



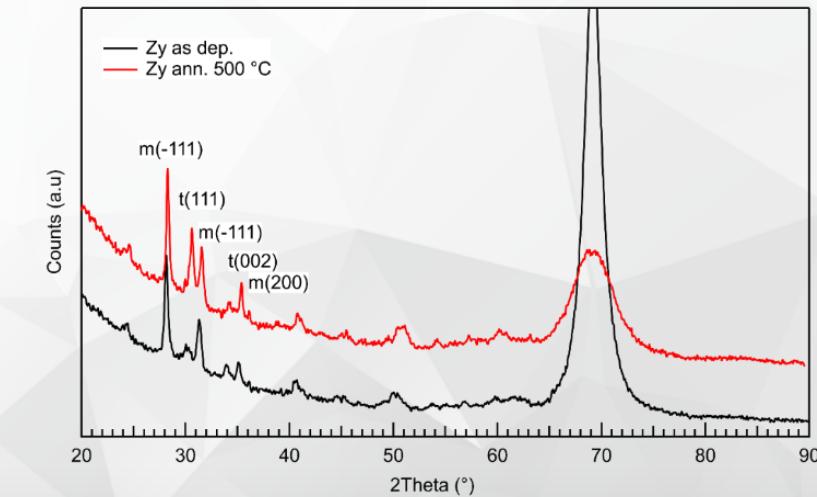
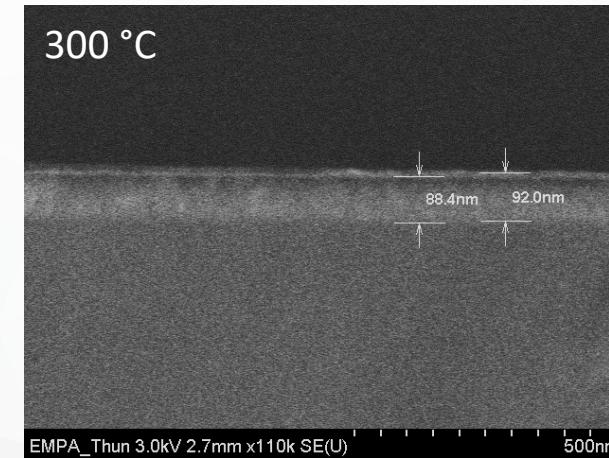
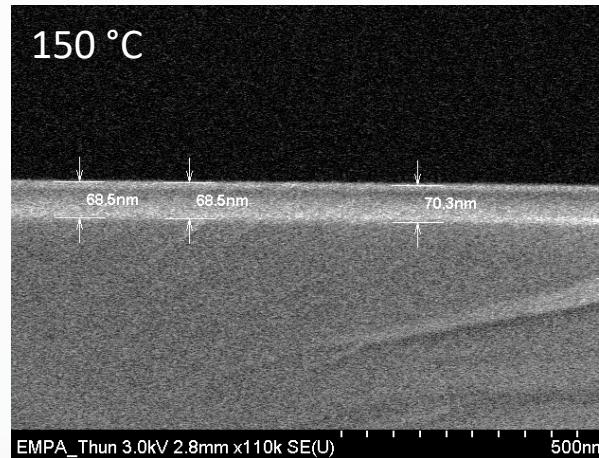
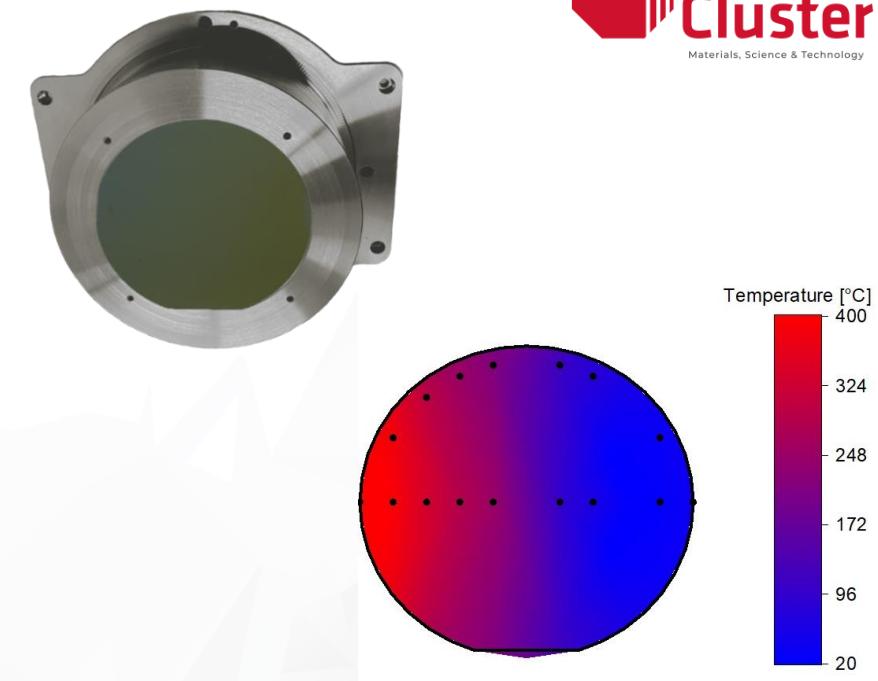
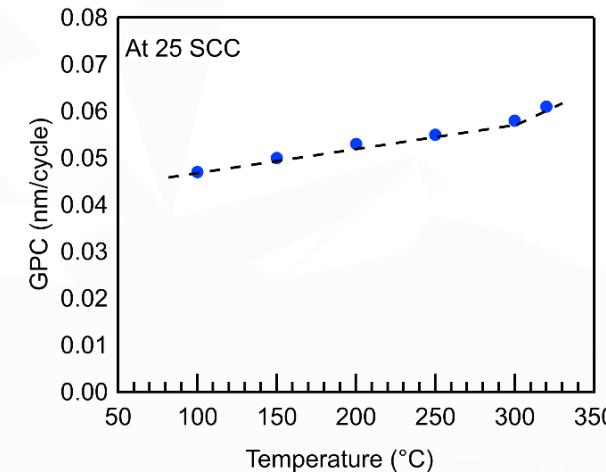
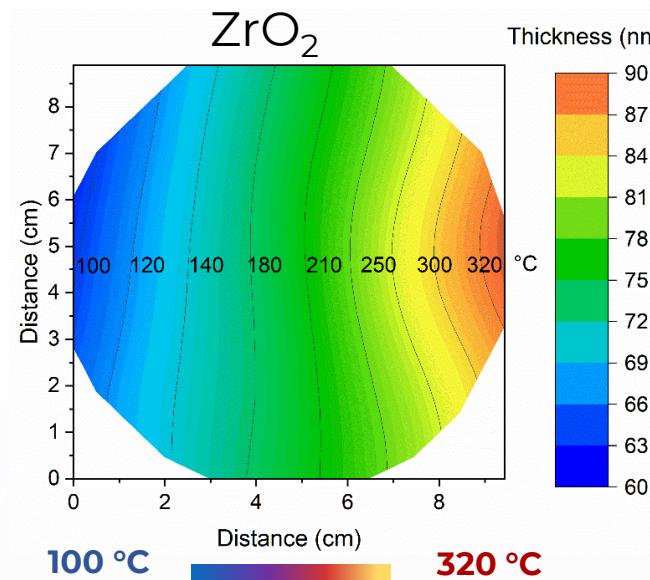
Electronics and Software

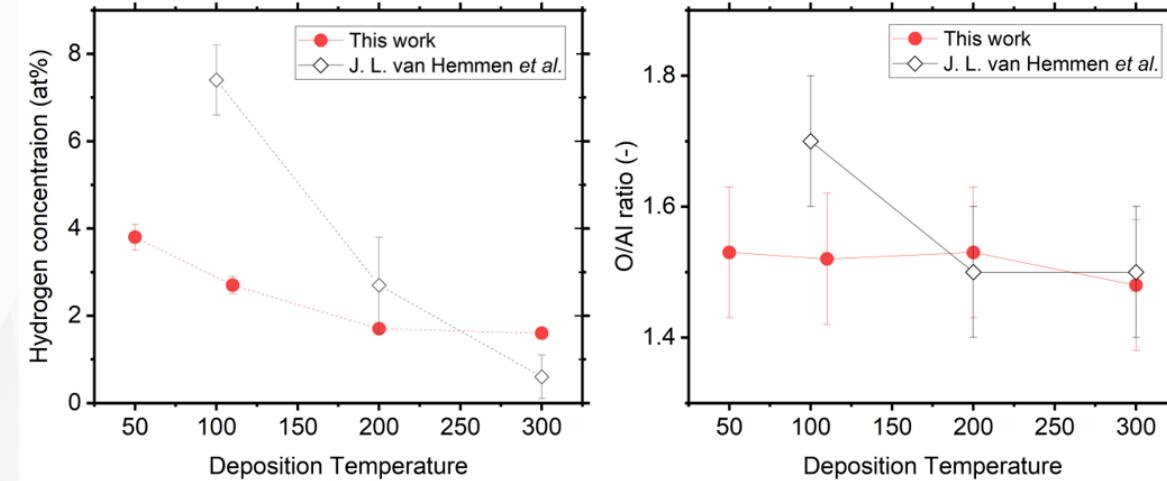
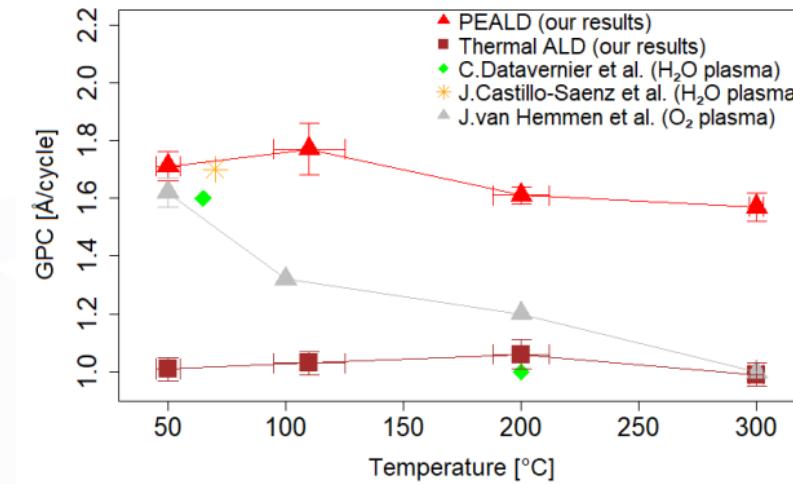
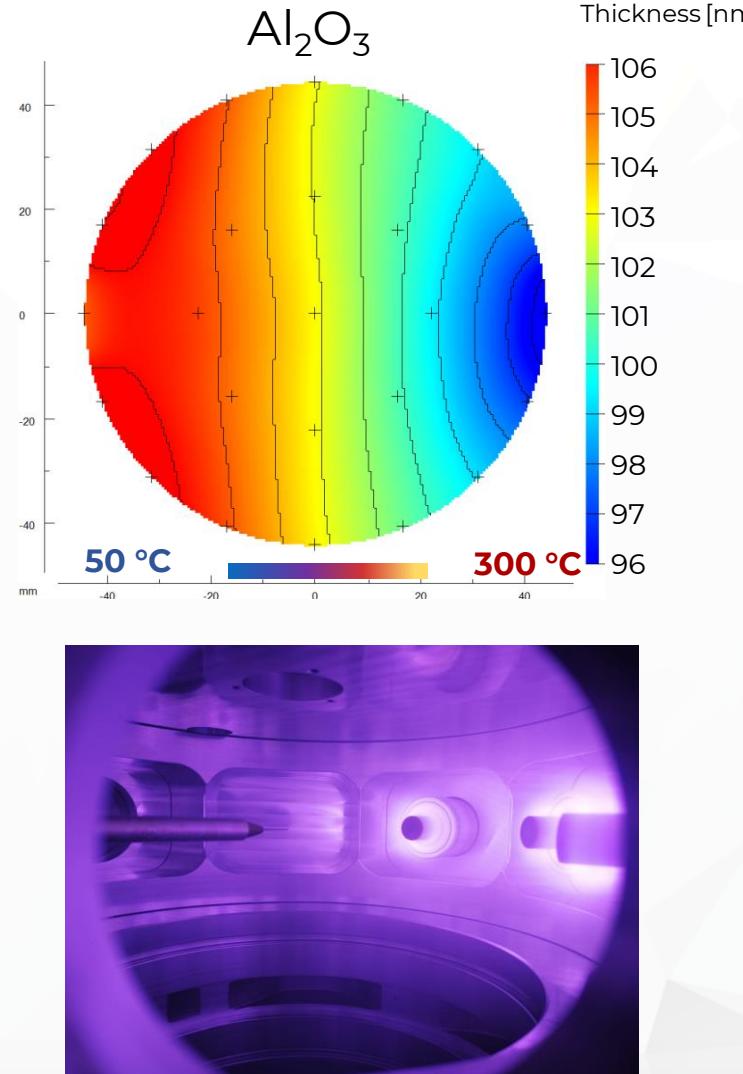
Modular and flexible to add new hardware



In-situ metrology

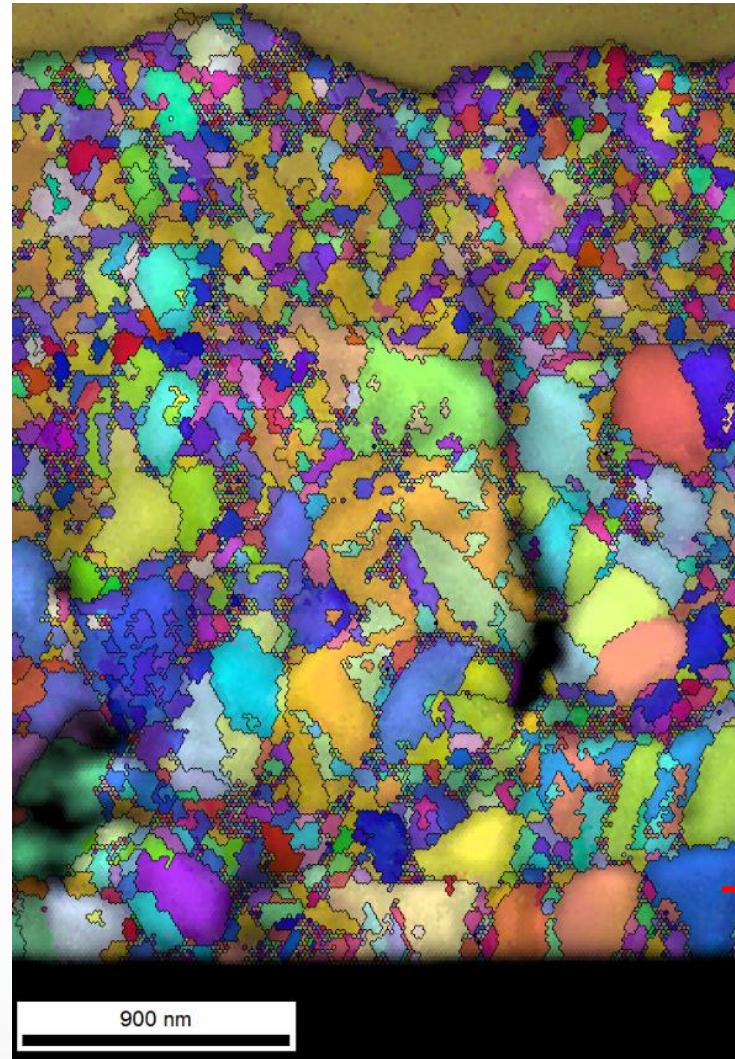
- In-situ stress wafer measurements
- OES
 - TOF MS (pga TOF)
 - QCM
 - In-situ ellipsometer
 - Langmuir Probe





PVD-ALD RESULTS

400 °C -RT

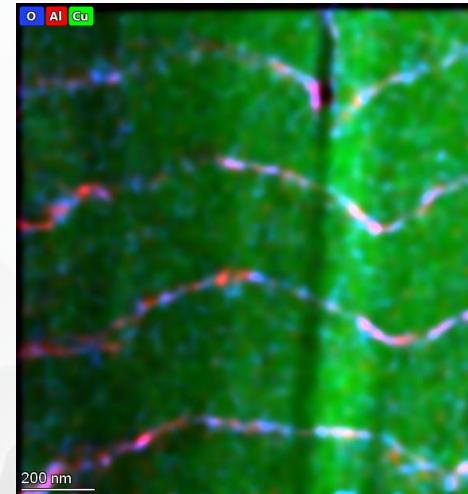
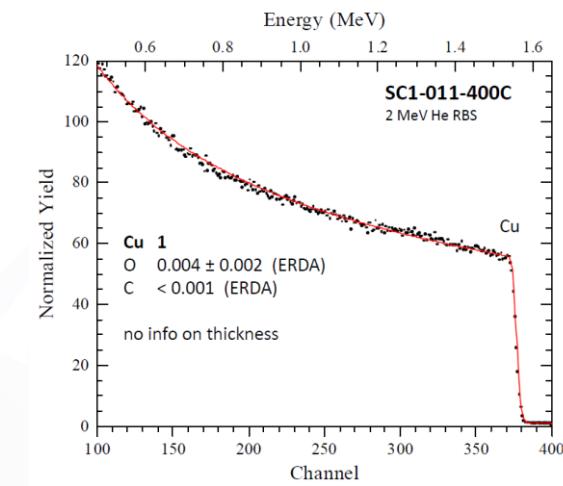
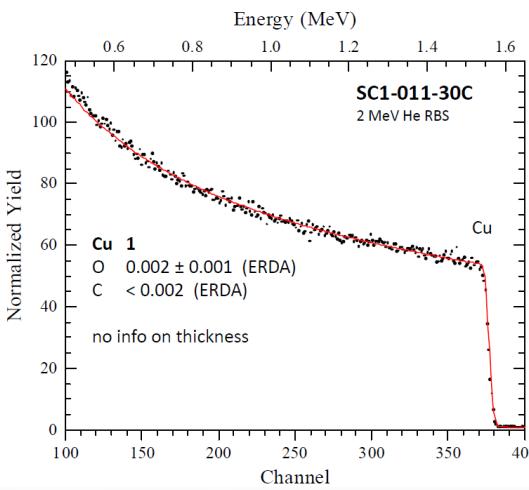


Graded Microstructure

RT
Fine grains

200 °C
Intermediate
grain size

400 °C
Coarse grains

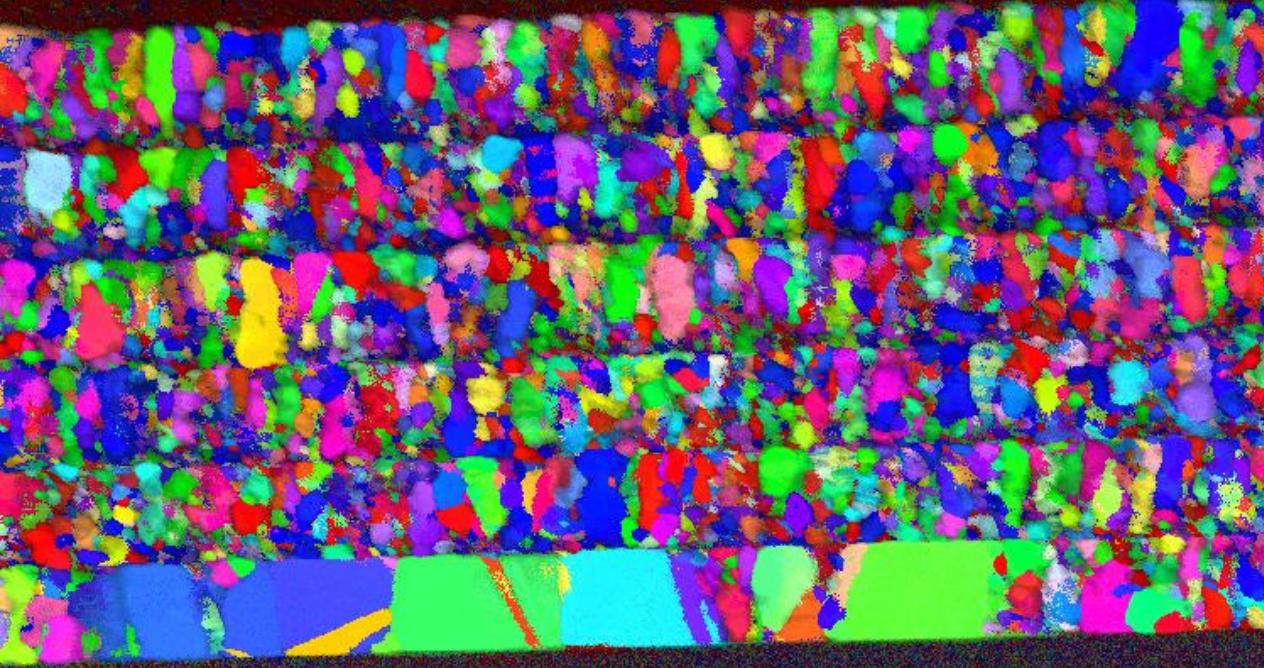


EDX and RBS data
show no oxidation or
contamination of the
metal film due to the
combination with an
ALD process

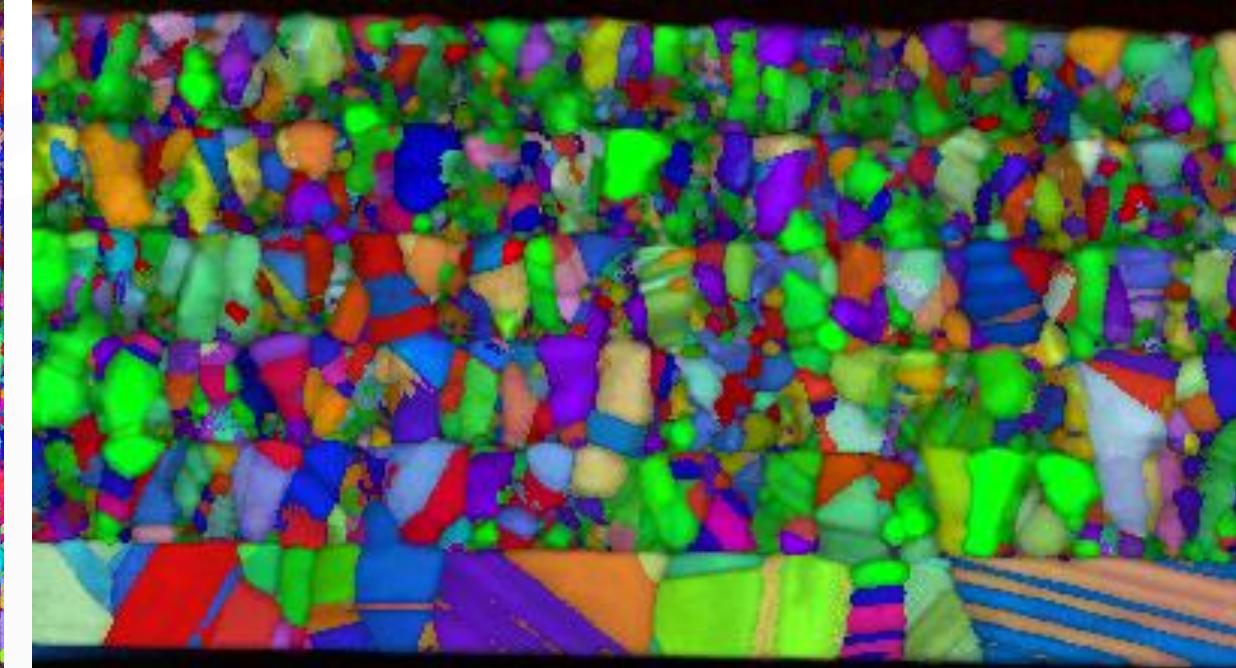
PVD-ALD

Cu-Al alloy (150nm) + 5 nm Al_2O_3

As deposited



Annealed 400 °C



- ALD and its importance in different markets
- ALD and its combination with PVD will play a major role in tailoring new coating materials for new and existing technologies in different sectors = Better Together
- Relatively new lines of research, combinatorial studies and applications of multilayered nanomaterials → High throughput R&D
- Scaling up processes and equipment

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Empa Team

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Ivo Utke
Johann Michler

BFH Team

Caroline Hain
Thomas Nelis
Sylvain Le Coultre

TOFWERK

STI

Stiftung für technologische Innovation
Fondation pour l'innovation technologique
Foundation for technological innovation

INFICON

SAIREM

GRITEC

G
GENCOA

be>advanced

VAT



Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra
Swiss Confederation
Innosuisse – Swiss Innovation Agency

Next seminars

Biel / Bienne

Quellgasse 21, Aula

16.3.2023 | Shaping Participatory Health Informatics Prof. Dr. Kerstin Denecke, Institute for Medical Informatics I4MI, BFH-TI

30.3.2023 | Mit dem Handy das Auto aufschliessen? Hardware Protected Confirmation macht es möglich
Prof. Dr. Benjamin Fehrensen, Institute for Cybersecurity and Engineering ICE, BFH-TI

6.4.2023 | Von der Laborbank zum Patienten – Erste klinische Resultate zur selektiven Netzhautherapie Christian Burri, Institute for Human Centered Engineering HuCE, BFH-TI

Biel / Bienne

Quellgasse 21, Aula

13.4.2023 | Intégration d'un ensemble complet de logiciels pour la conduite autonome Ahmed Hanachi, Institut pour la recherche sur l'énergie et la mobilité IEM, BFH-TI

27.4.2023 | Die digitale Transformation des Exportgeschäfts Prof. Dr. Paul Ammann, Institute for Data Applications and Security IDAS, BFH-TI

11.5.2023 | The Relevance and Hands-on Application of Biomedical Record Linkage in the Big Data Era Prof. Dr. Murat Sariyar, Institute for Medical Informatics I4MI, BFH-TI

1.6.2023 | Averaging Model for Feedback Control of Ultrasonic Transducers Diego Stutzer, Institute for Human Centered Engineering HuCE, BFH-TI

Burgdorf / Berthoud

Pestalozzistrasse 20, E013

23.3.2023 | Recycling von Traktionsbatterien aus Elektrofahrzeugen bei Librec
Denis Werner, Technischer Leiter, Librec AG

20.4.2023 | How Data Analysis Can Help to Better Understand the Degradation in PV Modules Prof. Dr. Jasmin Wandel, Institute for Optimisation and Data Analysis IODA , BFH-TI and Sara El Hassani, Institute for Energy and Mobility Research IEM, BFH-TI

4.5.2023 | TPV 5000 – Beitrag zur Defossilisierung des Verkehrs Dr. Albrecht Tribukait, CEO ad int., Silent-Power AG

25.5.2023 am Jlcoweg 1 | What is High Voltage Engineering about? Prof. Dr. Roman Grinberg, Institute for Energy and Mobility Research IEM, BFH-TI

8.6.2023 | Waghalsige Holzkonstruktionen unter Anwendung moderner Technologie neu denken Matias Penrroz, Institut für digitale Bau- und Holzwirtschaft IdBH, BFH-AHB