“Virtual PVD”: A Virtual Reality approach to explore PVD Magnetron sputtering

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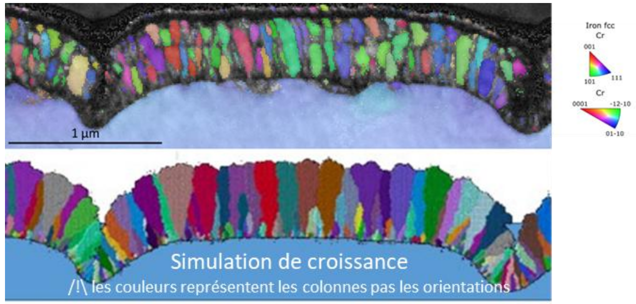
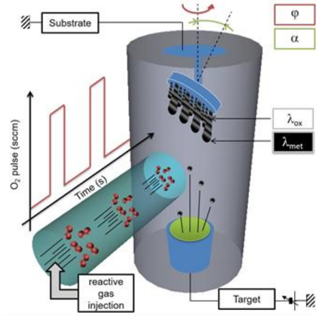
CONTEXTE



The (vacuum) physical vapor deposition (**PVD**):

- Uses: mechanical, micro-electronic, optical, chemical, decorative, etc.
- Films are columnar (most of the time), crystalline or amorphous, simple (metals, binary, ternary or more ceramics) or architectured (multilayer…)
- Multi-scale: from the Angström (atoms) to the meter (chamber) through a dozen of nanometers (column width), the micrometer (film thickness), a dozen of millimeters (substrates), a few centimeters (distance of flight), etc.
- Multi-physic: atomistic, chemistry, thermic, electric, etc.
- Take place in a closed and opaque chamber, under vacuum (< 1 Pa) with three main steps:
  - Vapor generation
  - Transport from the vapor source (« target ») to the substrate (part to coat)
  - Condensation and growth of the film



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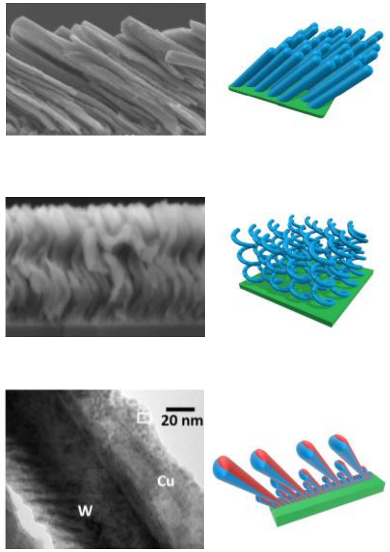


PROPOSED APPROACH

Typical working methodology:

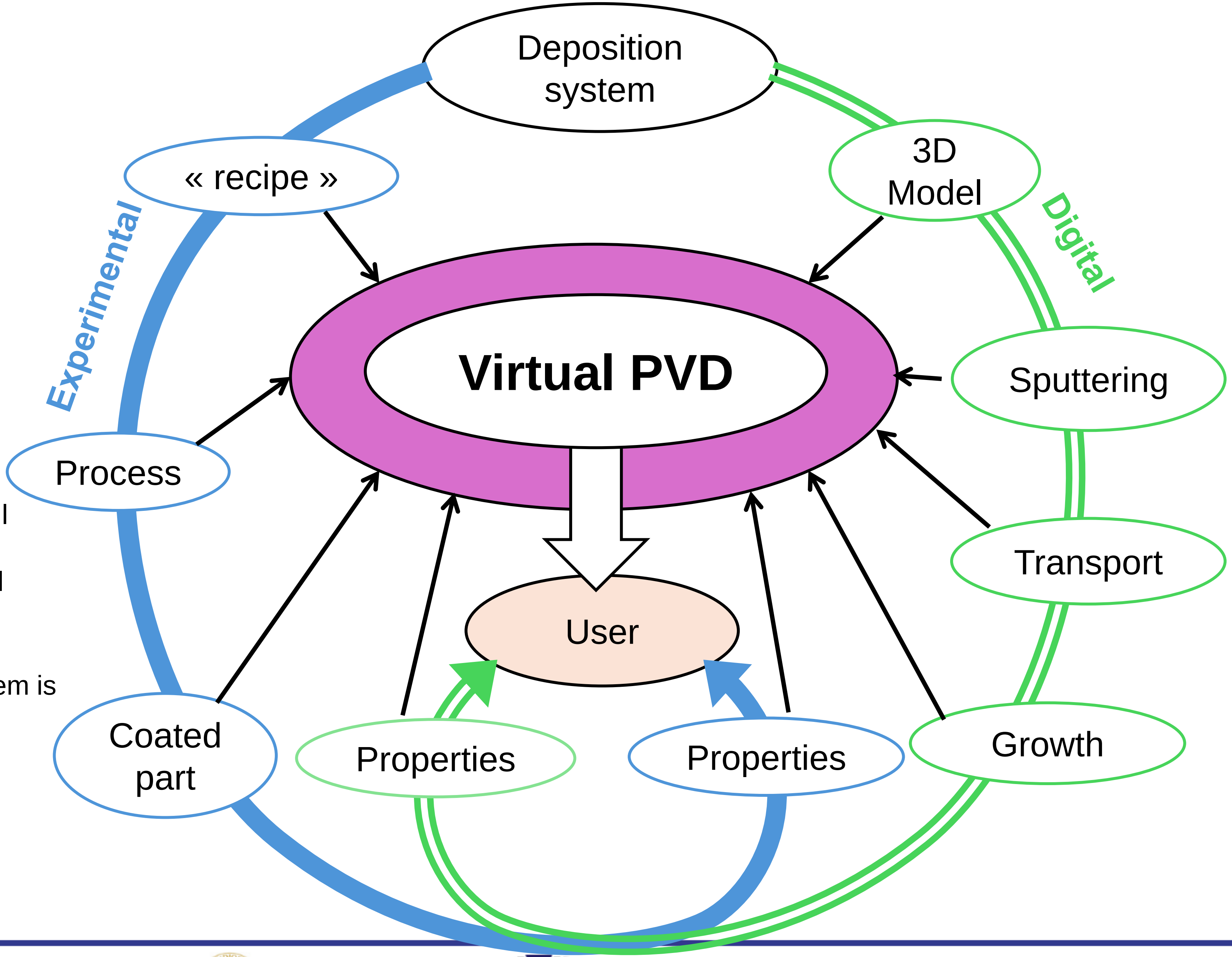
- Experimental
- Digital

→ Alone or combined (in full or partial…)

Problematic:

- No overall vision
- Hard to manage and analyze the full dataset
- Human perception of some physical phenomenon is impossible
- No interaction
- Training on the real deposition system is not easy

→ Need of a Virtual PVD



STATE OF THE ART

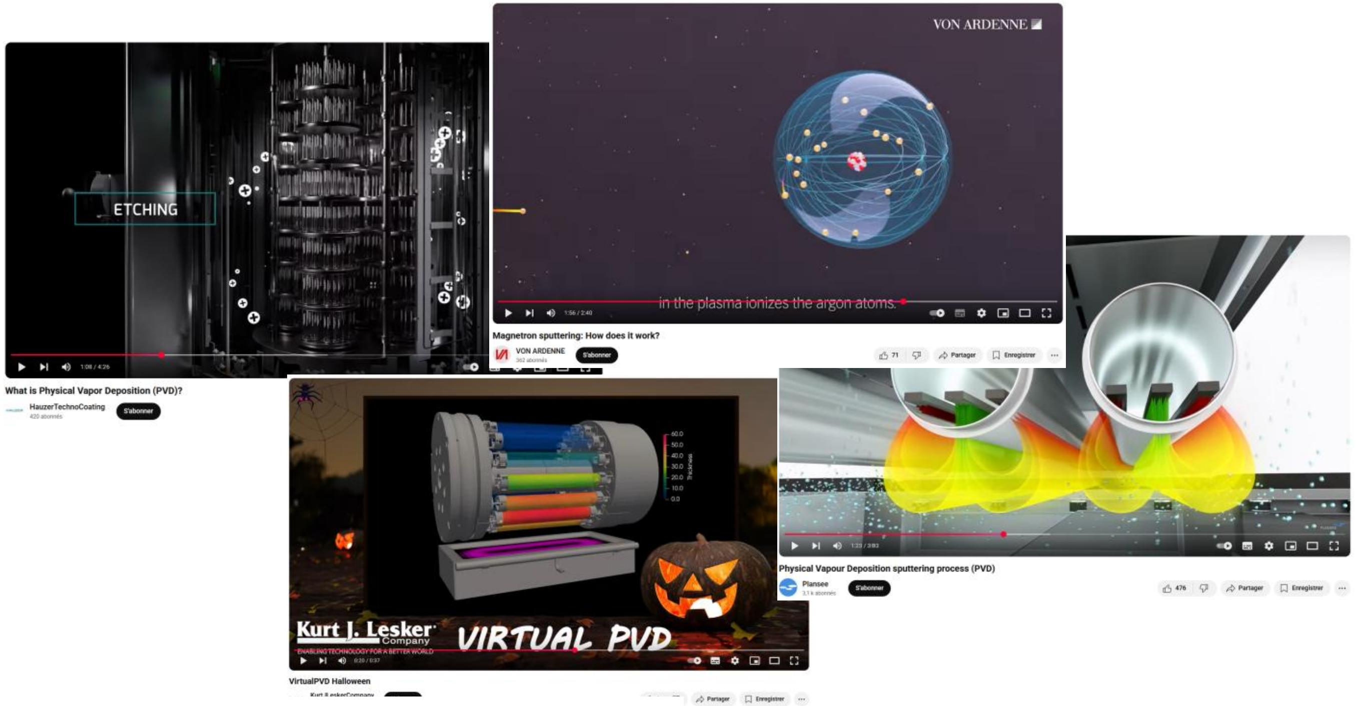
In the PVD field are found:

- Commercial videos

  → PVD system manufacturers

  → Illustrate the physics of the deposition process and its various applications.

  → Present simulation tools



- A VR application for the D.A.U.M. platform (Deposition and Analysis in Ultra-vacuum for nano-Material).

  → Not fully dedicated to PVD but illustrate some experiments on the system

- A web site (2003) with videos and 3D animations and a section dedicated to PVD deposition: not further developed.

→ Need of a comprehensive and scientifically-based virtual application for PVD.

VIRTUAL PVD : MAIN MENU

Two categories (Ex-situ & In-situ) of virtual universe are proposed for different purposes:

→ Multiscale perception and interaction.

→ Different objectives.

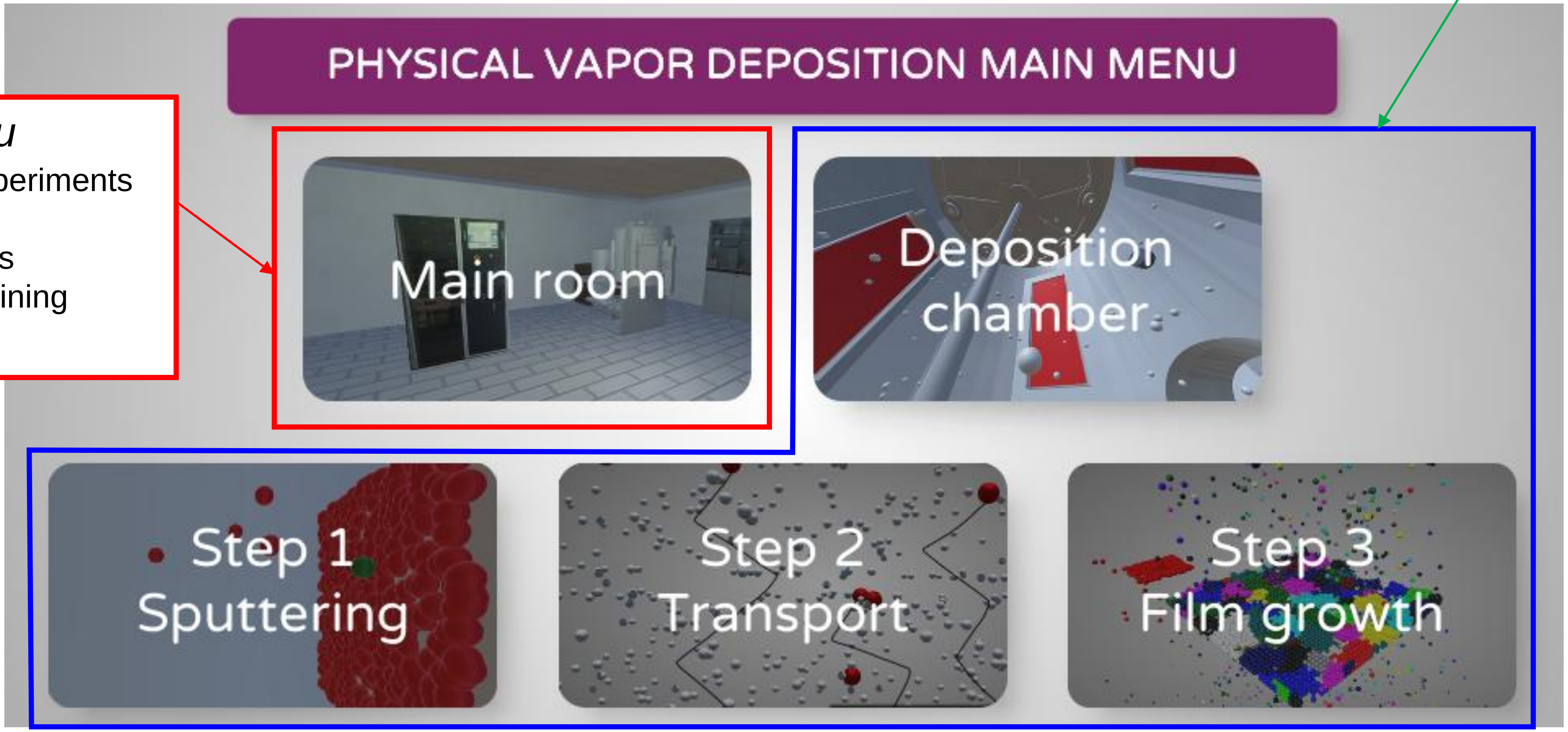
→ Different kinds of training.

In-situ

- Multi-scale visualization and immersion
- Illustration of physical phenomenon
- Scientific training

Ex-situ

- Real size experiments
- Components manipulations
- Technical training



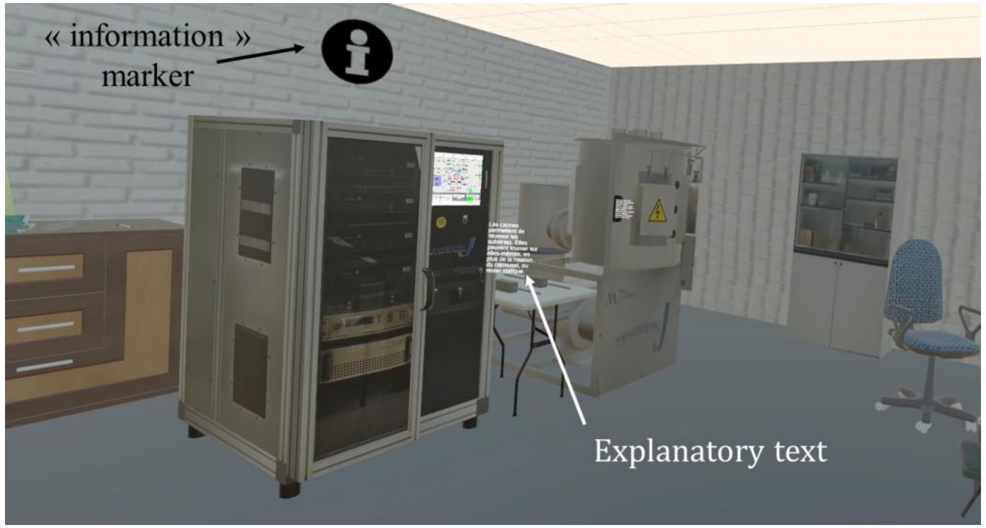
VIRTUAL PVD : EX-SITU

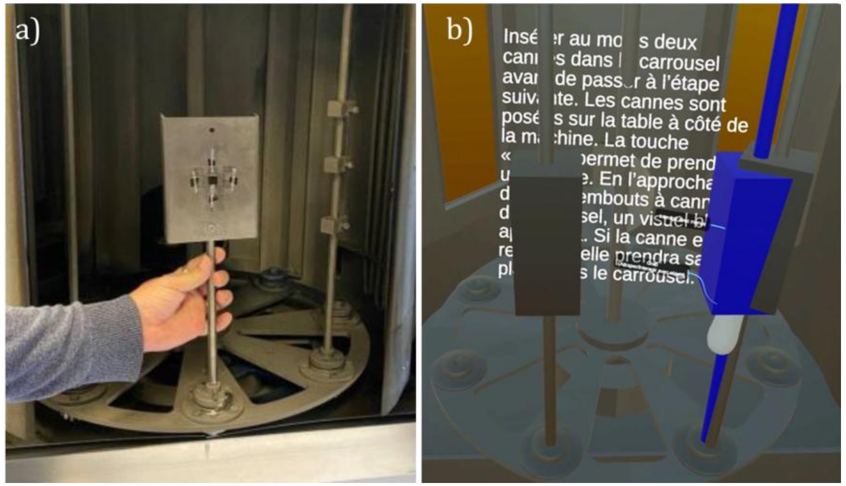
- Real-life scale and "realistic" environment
- Natural interactions with objects.

Two main functions are proposed:

- Navigation in the laboratory, safe exploration of the deposition system (risks: noise, electrical, thermal, mechanical, etc.), and discovery of its various components, without disturbing the operation system.

  → Outreach to the non-scientific public
  → General PVD training aimed at technical and scientific audiences.





- Manipulation of some components and experiment operative routines:
  - Opening and closing the chamber
  - Loading and unloading samples
  - Maintenance operations (cleaning, changing a target, etc.)

  → Practice technical skills and gestures.

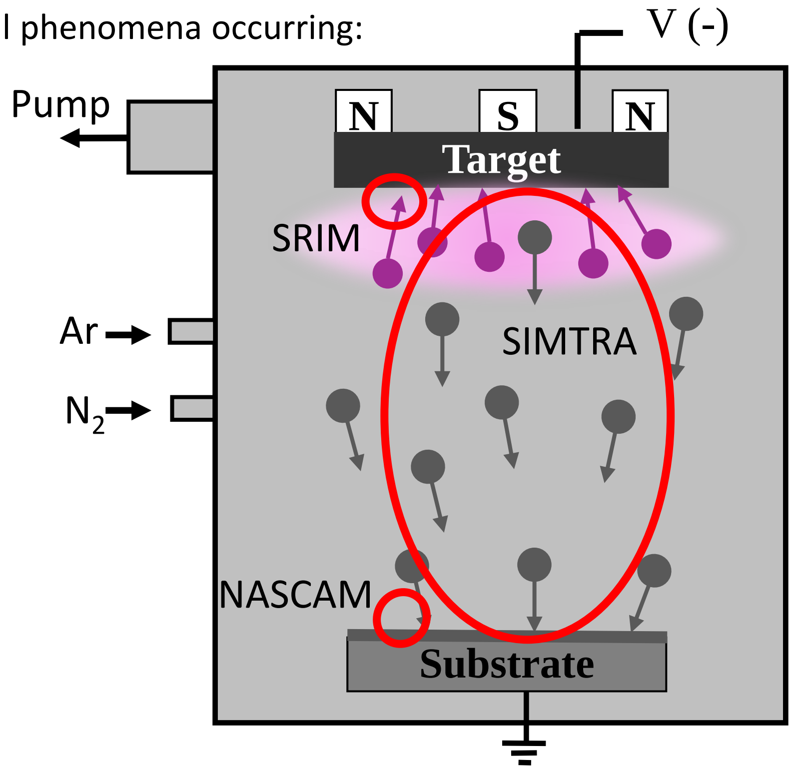
VIRTUAL PVD : IN-SITU

- Unrealistic size relatively to the scale of the real system, ranging from a few centimeters to a few tens of centimeters.
- Immersion in an environment naturally inaccessible to humans (vacuum) and gravity is not always respected.
- Interaction with physical entities (molecules and atoms) : increase of their size and decrease of their number.

The objective of this module is to visualize the steps of the deposition process and the physical phenomena occurring:

- Pumping of the initial atmosphere,
- Injection of working gas (Argon),
- Creation of plasma,
- Sputtering of the target,
- Transport of the sputtered atoms to the substrate,
- Film growth on the substrate,
- Film properties.

→ Based on physical laws and data from process instrumentation and simulations (SRIM, SIMTRA, NASCAM) of the different steps.



VIRTUAL PVD : IN-SITU

PROCESS CONTROL

1. Learn reading the control panel of the real system with the different components, control parameters, safety features, etc.

2. Display graphs illustrating the process parameters over time (pressure, discharge voltage, current).

3. Navigation in the app

Control panel of the real deposition system

Graphs (experimental data):

- Pressure,
- Voltage,
- Current.

Navigation panel between the different steps: initial state, pumping, gas inlet, sputtering, transport, and growth.
+ return to the main Menu

Control panel of the real deposition

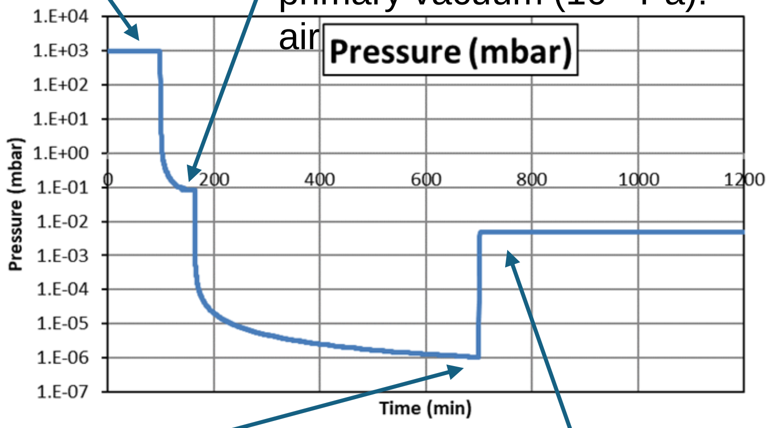
VIRTUAL PVD : IN-SITU

1. Visualize the different atmospheres in relation to the process steps and the control graph.

2. Learn and identify the molecules : relative size, bonding angles (180, 120, or 109.5°), color code (Corey-Pauling-Koltun model)

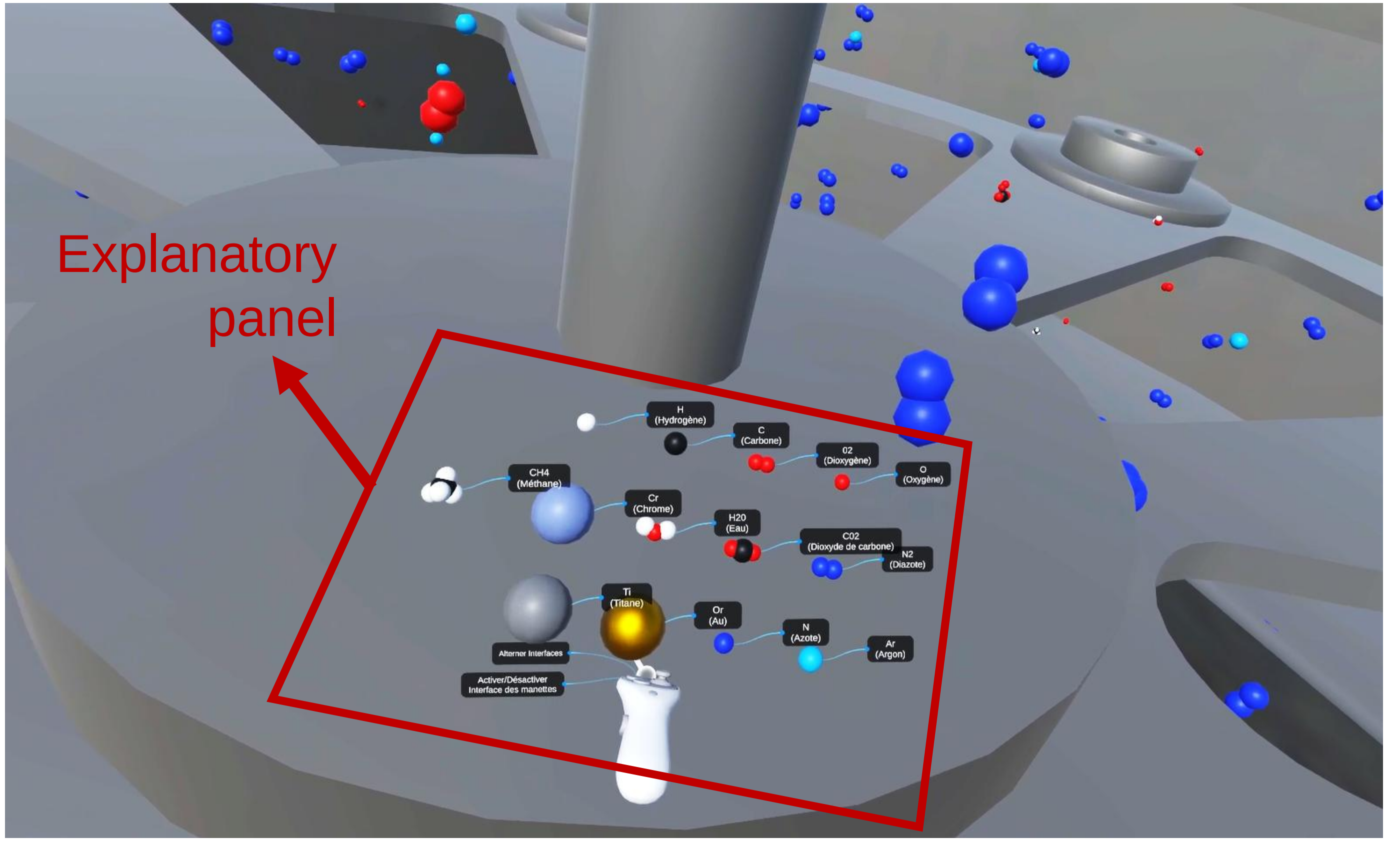
Atmospheric pressure (10^5 Pa): air

Transition pressure, primary vacuum (10^{-1} Pa): air



Residual pressure, secondary vacuum (10^{-4} Pa): H_2O traces

Working pressure (10^{-1} Pa): Ar, reactive gas, metallic atoms



VIRTUAL PVD : IN-SITU

Sputtering occurs at a given pressure (working pressure 0.1 Pa) with argon (eventually reactive gas) and with a electric discharge in presence of a magnetic field.

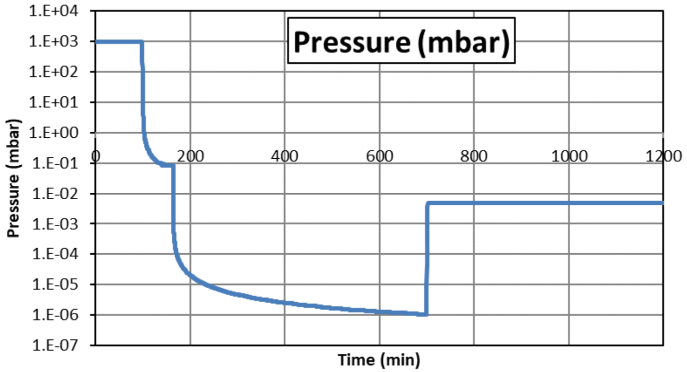
Several phenomenon occurs and can be visualized:

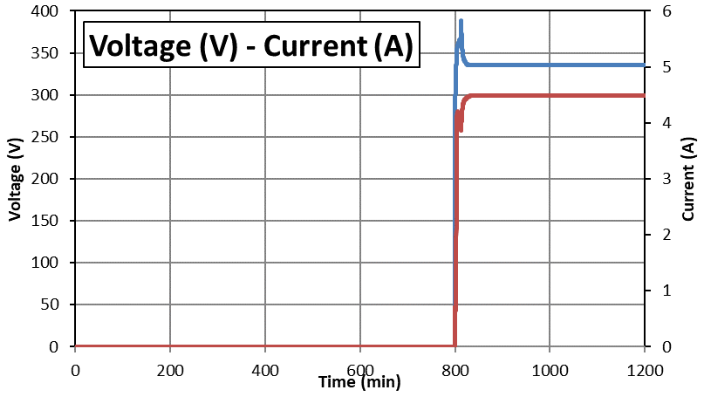
- Ignition and maintain of a plasma (a, c):
  - → Argon ionization, photonic emission

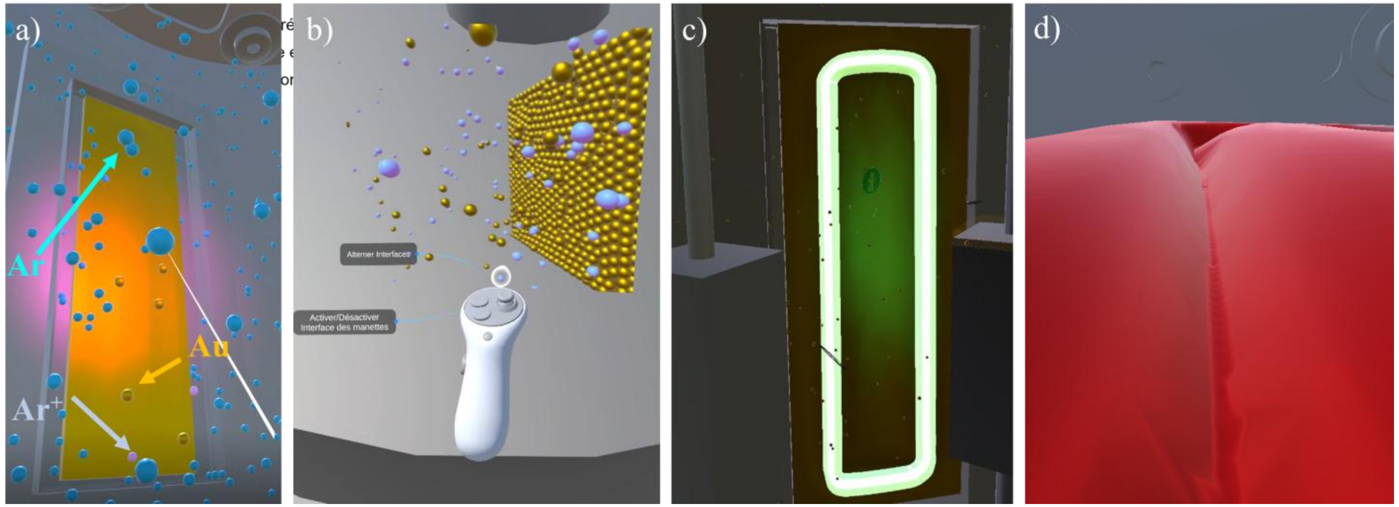
- Acceleration of the Ar^{+} ions toward the target (negatively polarized) (a)

  → Cascade collision in the target subsurface and metallic atoms ejection (a, b)

  → Wear of the target following the magnetic field (d)





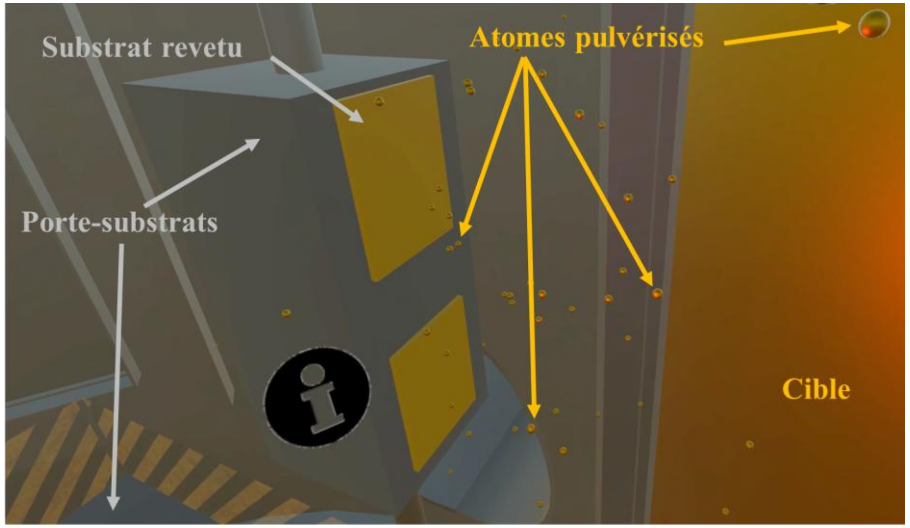


VIRTUAL PVD : IN-SITU

TRANSPORT AND GROWTH

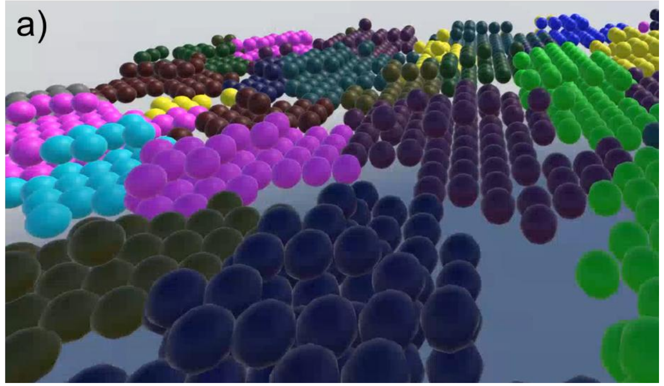
The metallic vapor flight through the chamber:

→ Condensation sur les on the walls (including the substrates) and growth of the film.

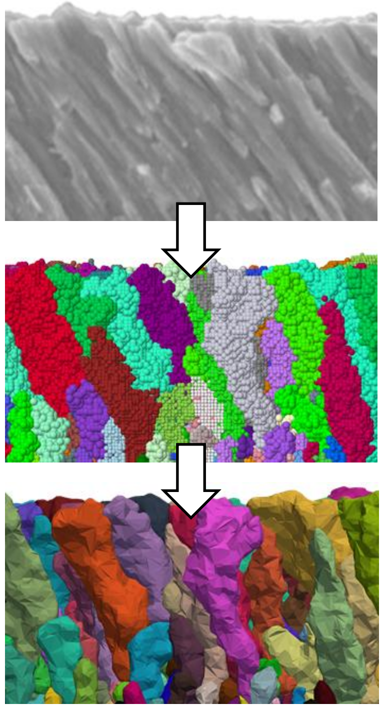


→ Visualize the growth at atomic level

a)



b)



Elastic collisions during the flight:

→ Changes in direction et energy loss

→ Visualization of the flux density and properties (perspectives)

Perspectives: visualize and interact with the columnar microstructure (nano- to micrometric scale)

→ Films properties

CONCLUSION ET PERSPECTIVES

To summarize…

- A virtual reality application dedicated to the PVD vacuum process was proposed.

  The prototype includes two modes:
  - Ex-situ, in the surface processing laboratory, at real-size: discovery of the system and its environment and technical training.
  - In-situ, in a “hostile” environment, at multiple scales: discovery of the physical phenomena occurring during PVD: scientific training.

- Data comes from measurements obtained from the real system as well as numerical simulations.

- Work was performed by mechanical engineer students, M1 and M2 master students (immersive and 3D technologies), and PhD (physic).

Future works:

- Integrate a larger volume of data from experimental measurements and numerical simulations .

- Develop training scenarios in terms of training and experiments (with augmented reality?)

- Experiments with participants students, academics, and industrials in the field of PVD

  → Scientific and technical validation.

Thank you for your attention

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