in-situ SEM Robotic-based Selection, Manipulation and Characterization of 3D Microscale Particles

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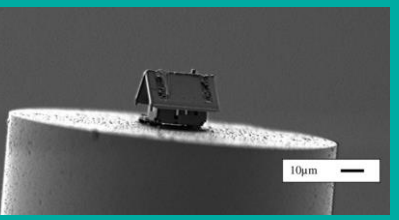
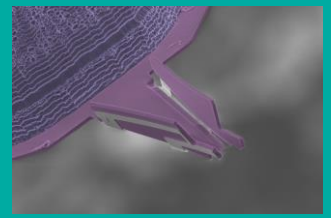
Cédric Clévy, Professor, FEMTO-ST, Franche-Comté University

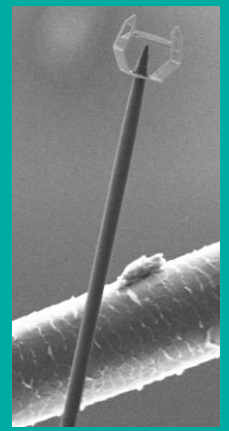


[J. Vac. Sc. 2018]

[Opt. Cont. 2022]



[Adv. Mat.. 2021]



[RA-L. 2021]

Part of the **DyNaBot** project, funded by the ANR.

Context & motivations of the works

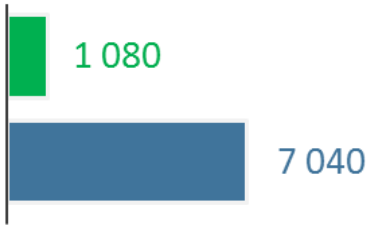
Total energy consumption worldwide

Holmberg K, Erdemir A.
Friction 5 (2017) 263-284

3% Wear

20% Friction

CO_2 emissions
($MtCO_2$)

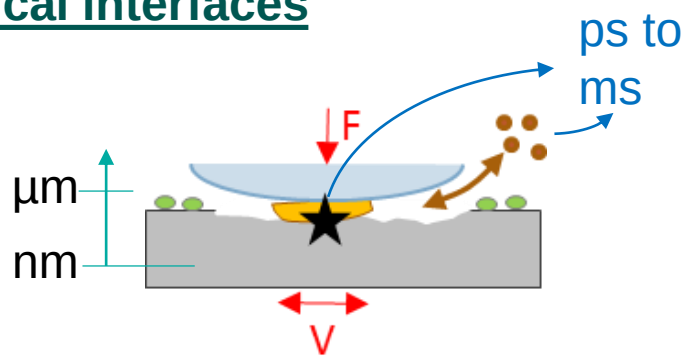


Energy saving and greehouse gas reduction ?

Contact issues and tribological interfaces

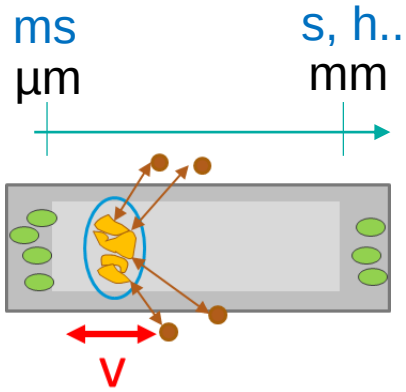
2 bodies in contact
+
an interphase is created during friction

Mechanical and physicochemical properties influenced by
- interactions with the environnement
- particle detachment and wear



Spatial scale

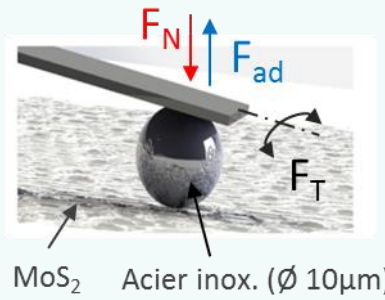
Time scale

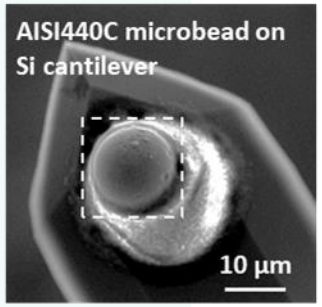


Context & motivations of the works

=> Surfaces coated with MoS2

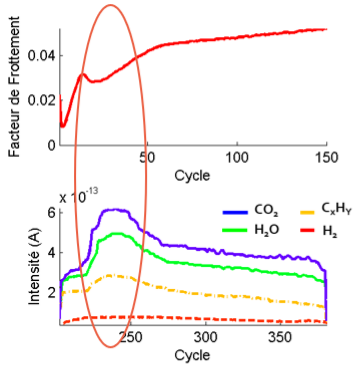
➢ Nano-tribology

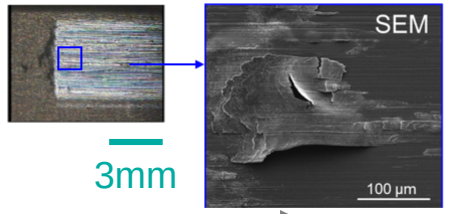


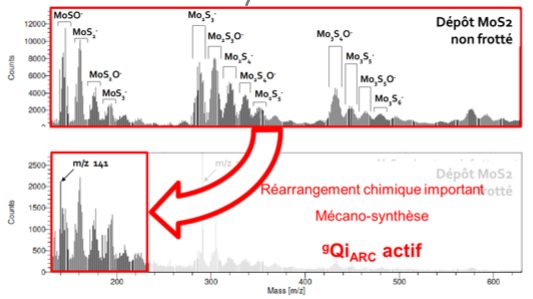


[S. Pajovic, Adv Eng Mat (2017), P. Serles Adv Mat Inter (2020), T. Arif Adv Mat Inter (2019) & Trib Int (2021)]

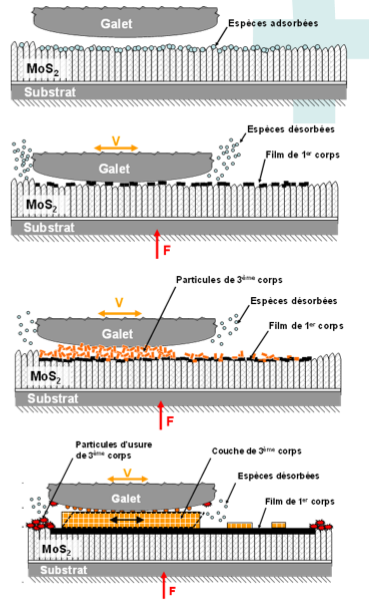
➢ Macro-tribology







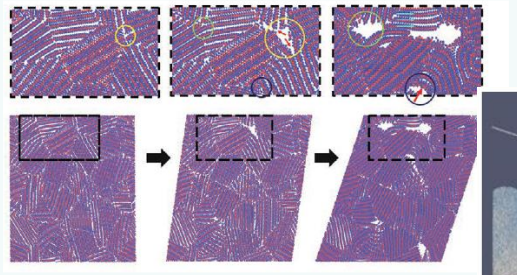
ToF-SIMS
Top surface chemistry

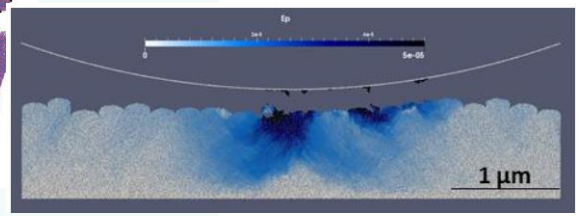


[G. Colas, et al Tribo Int (2013), Wear (2013) & (2015), ACS Appl Mat Interf (2018)]

➢ Molecular dynamics

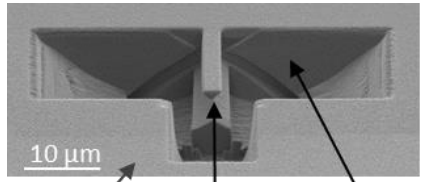
➢ & DEM

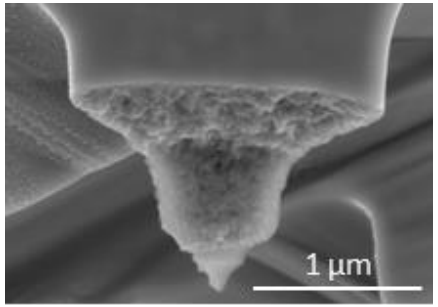




[Colas, ESMATS (2017), P. Serles Adv Func Mat (2022)]

➢ Indendation ; AFM based bending test





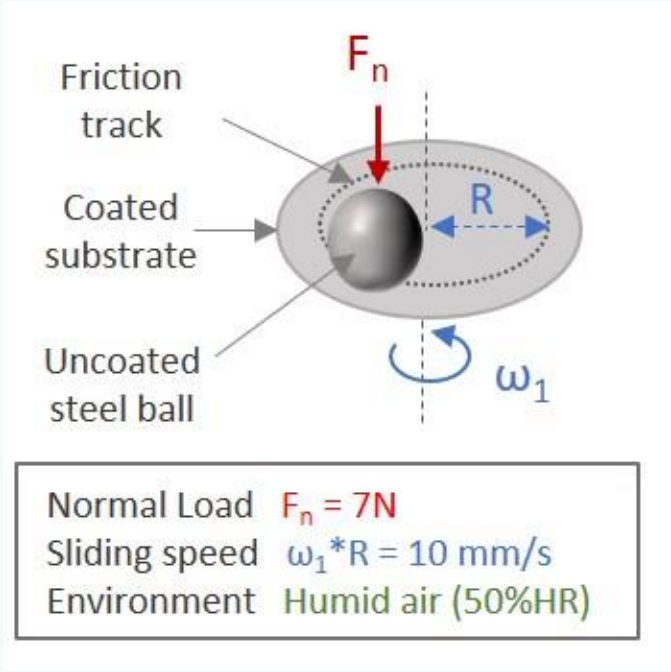
[G. Colas, et al Jour Phys Solids (2019)]

➢ Mechanical properties of 3rd bodies & particles : missing

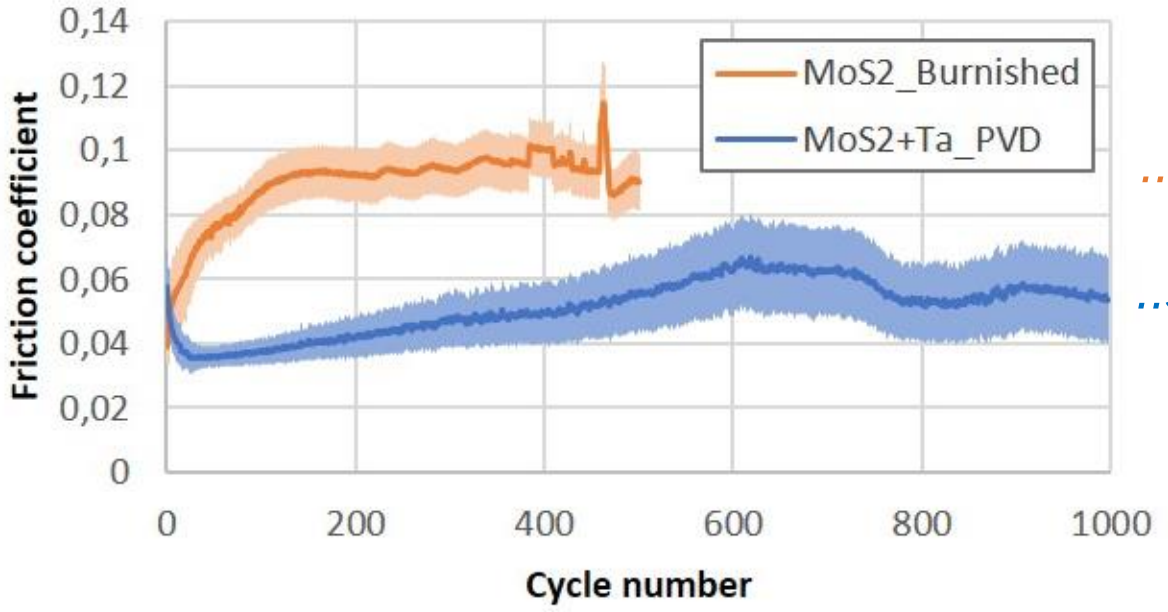
Context & motivations of the works

=> Surfaces coated with MoS2

Macroscale Friction tests



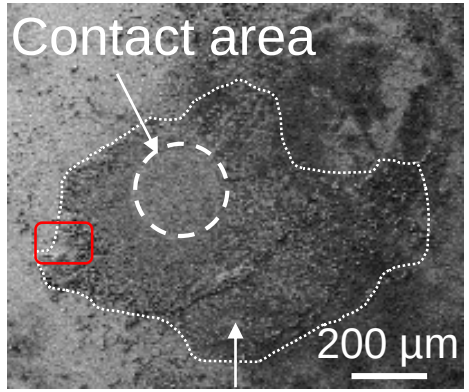
Normal Load	F_n = 7N
Sliding speed	ω_1*R = 10 mm/s
Environment	Humid air (50%HR)



Particle…

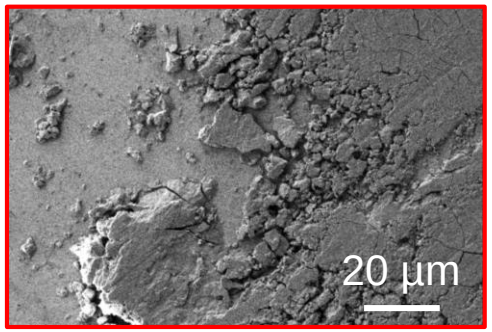
..stiff & brittle

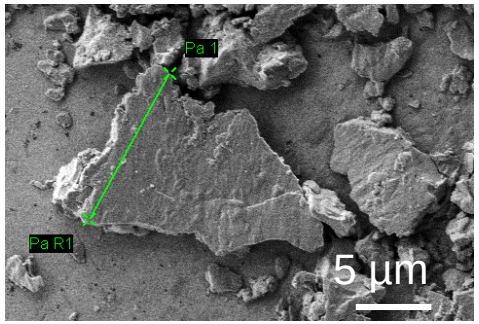
..soft & ductile



Ejected particles

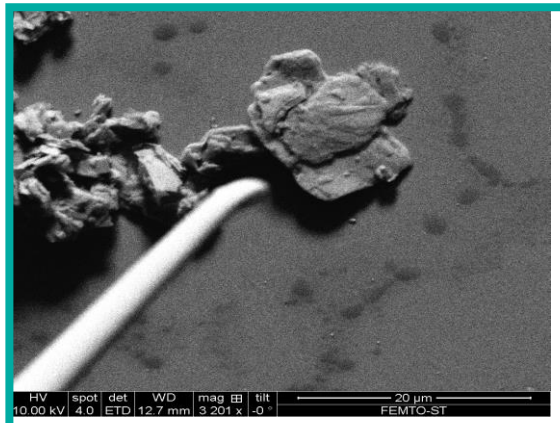
SEM analysis / particle selection on the ball





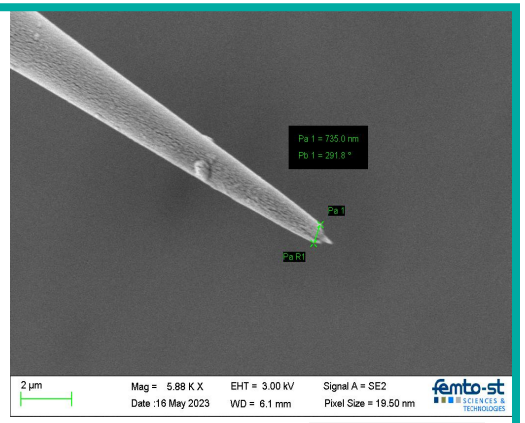
➢ 2 different type of 3rd body particles from MoS2 & MoS2+Ta

MAIN TOOLS AND TIPS



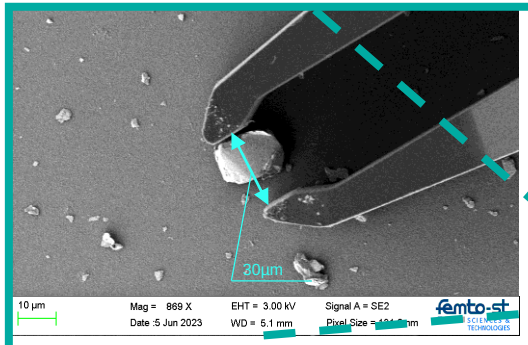
Metal-based probe

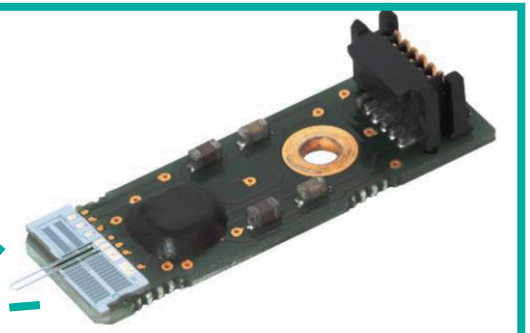
Diameter of 3µm



Metalized glass-based fiber probe

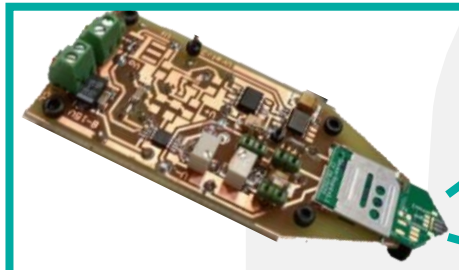
Diameter of 0.7µm

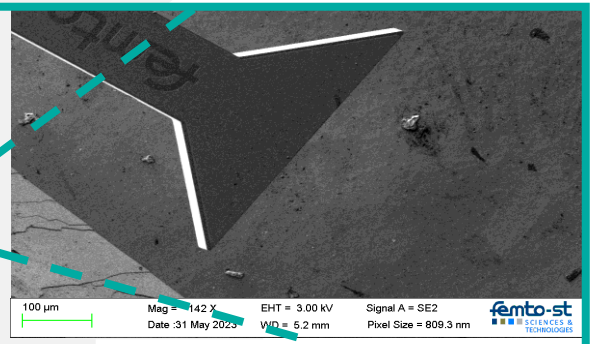




Femto-Tool Ft-G32 micro-gripper (actuation and sensing)

Thickness of 50µm



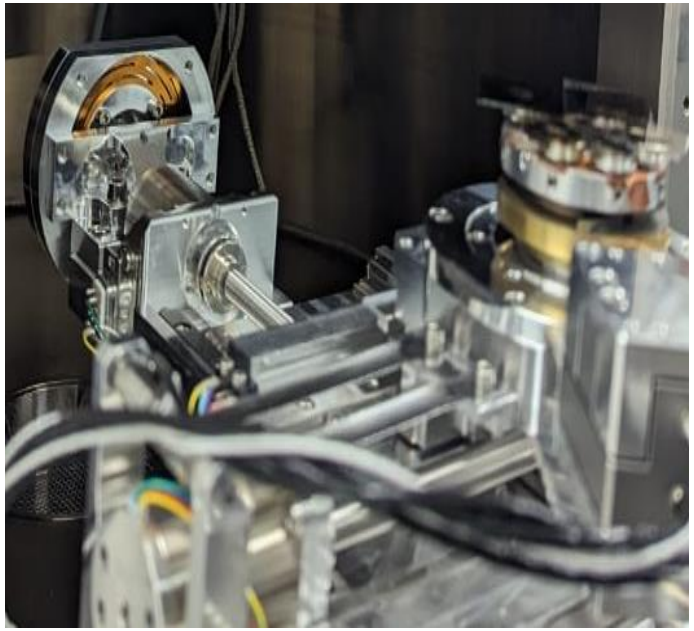


SENSITIPS micro-sensor

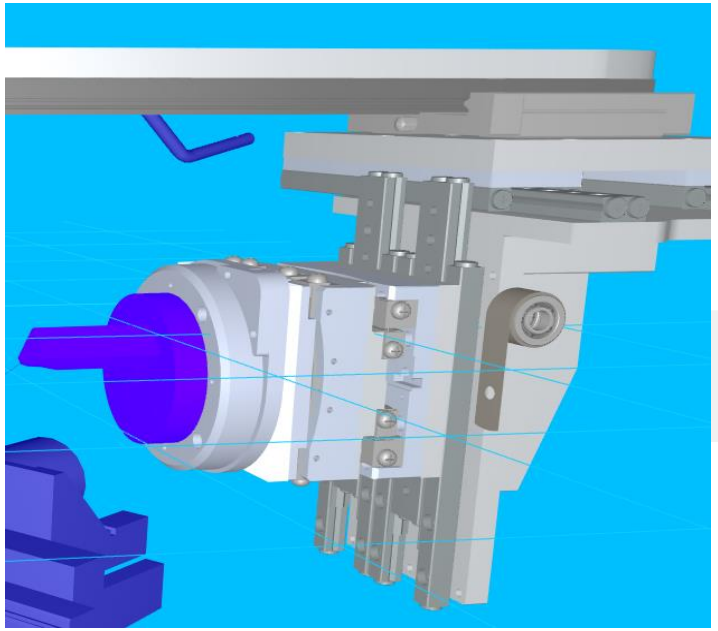
(resolution <1µN)

Thickness of 40µm

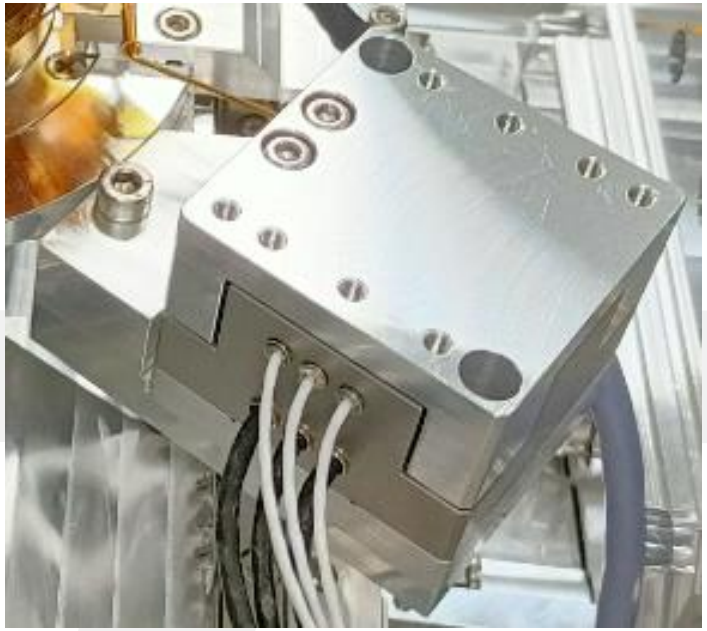
MAIN ROBOTIC SYSTEM USED IN THE SEM



5 DOF **sample holder stage**
3P2R (Precision of 1µm, 0.1 m°)
Grain platform holding
(ZEISS)



6 DOF **SEM Robot**
3P3R (Precision 10nm, 1 µ°)
Long ranged manipulation
(SmarAct)



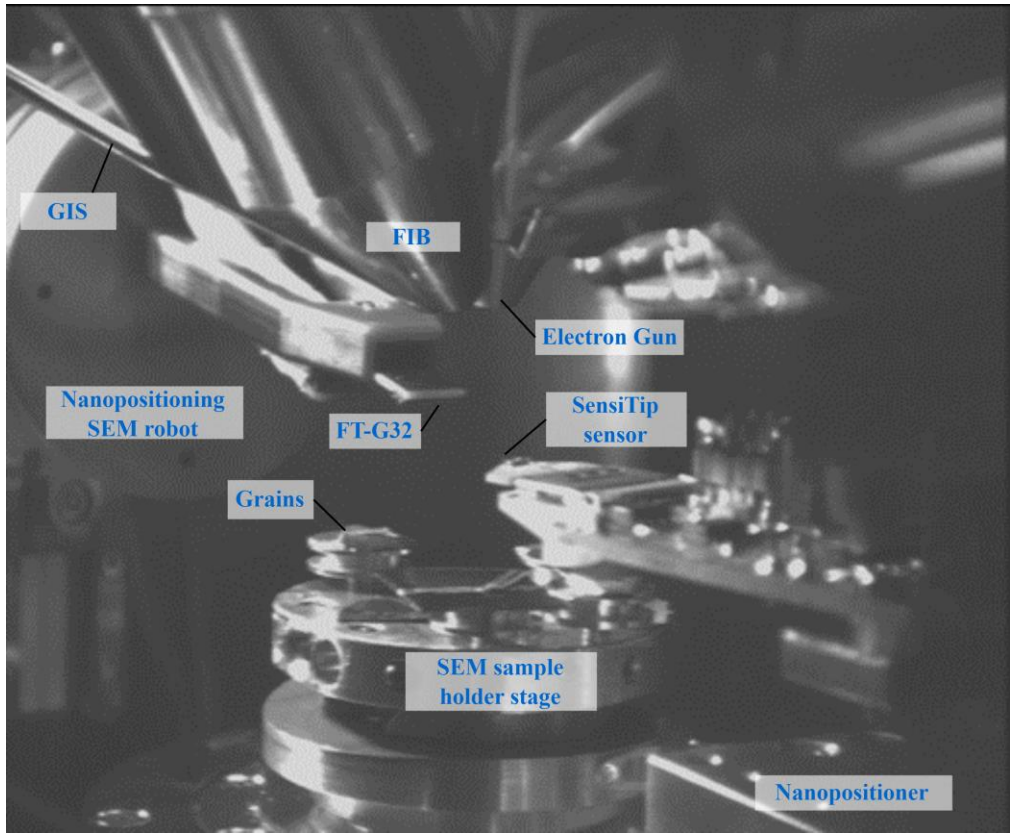
3 DOF **Nanopositioner**
3P (Precision 2 nm)
Fine manipulation
(Piezosystem jena)

Objective and Strategies

Achieve a first quantification and manipulation of intricate 3D structured micro scaled particles in-situ (SEM), directly from the friction track vincinity

Particles resulting from friction of MoS_2 grains based coatings.

- 10 µm < lateral size < 25 µm
- 3 µm < thickness < 10 µm



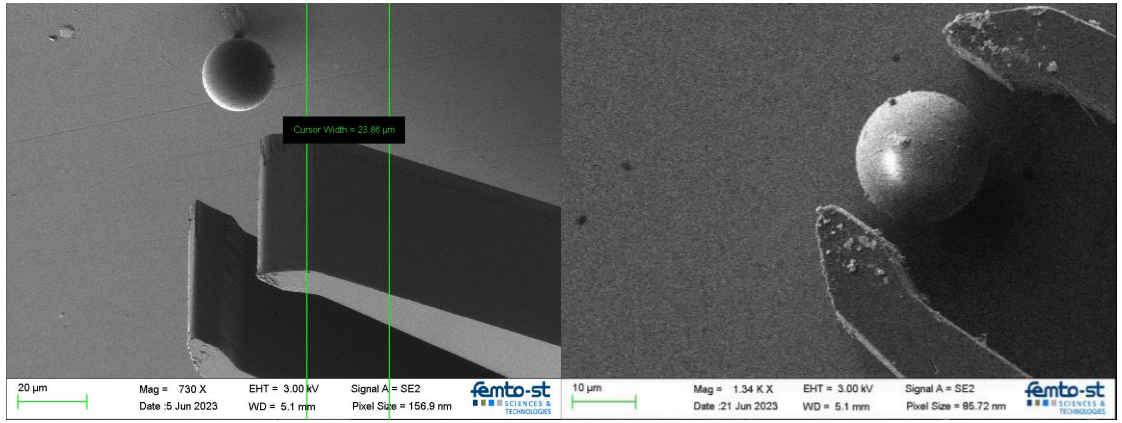
Challenges:

- Sequence of tasks (particle selection, isolation, grasping, testing)
- Grains are 3D with complex internal structure
- Force & displacements to be measured but what range?

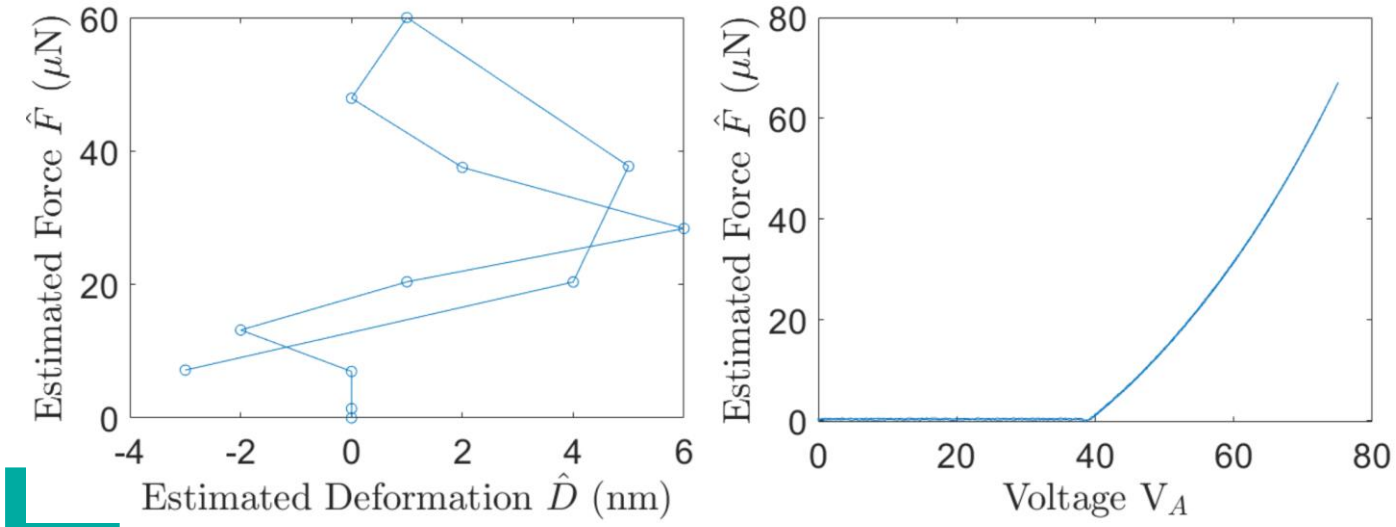
Approach:

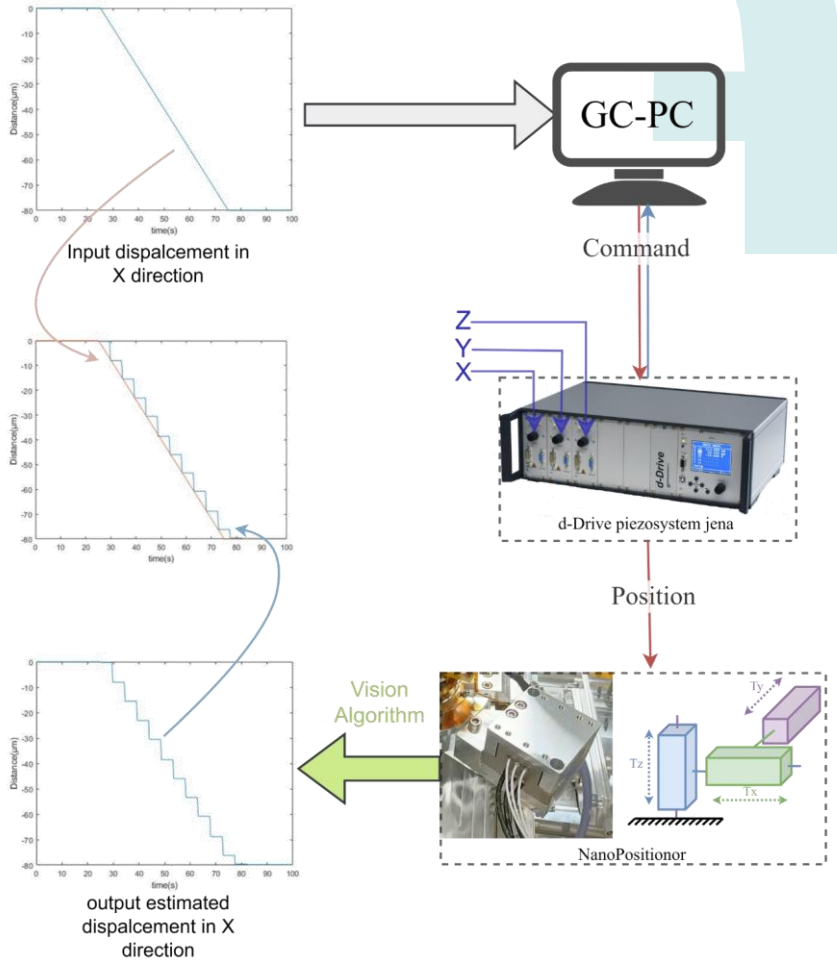
- Set of tools and methods that can be combined into a single sequence inside of a SEM
- Comparison of raw materials MoS2 and MoS2/Ta

ALGORITHM TO EVALUATE FOR THE COMPONENT DEFORMATION



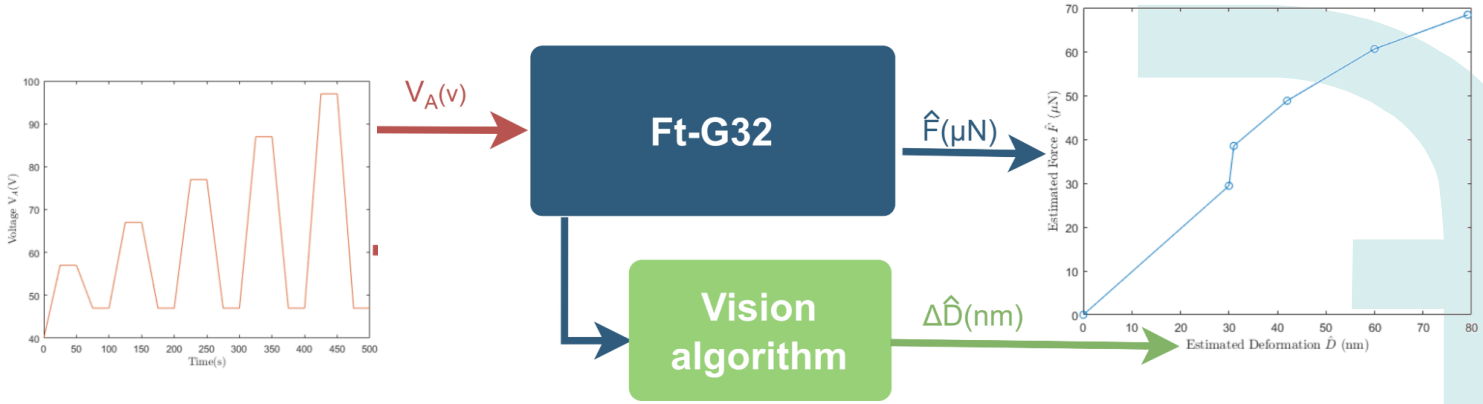
Rigid Si beads application

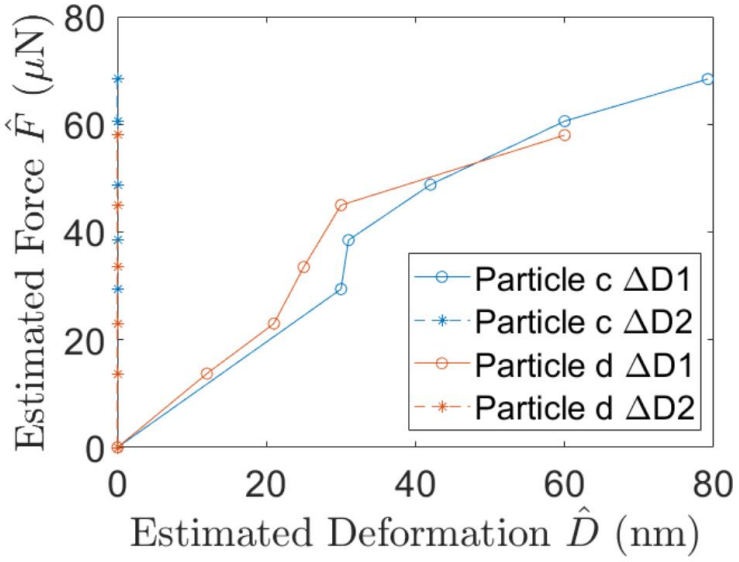




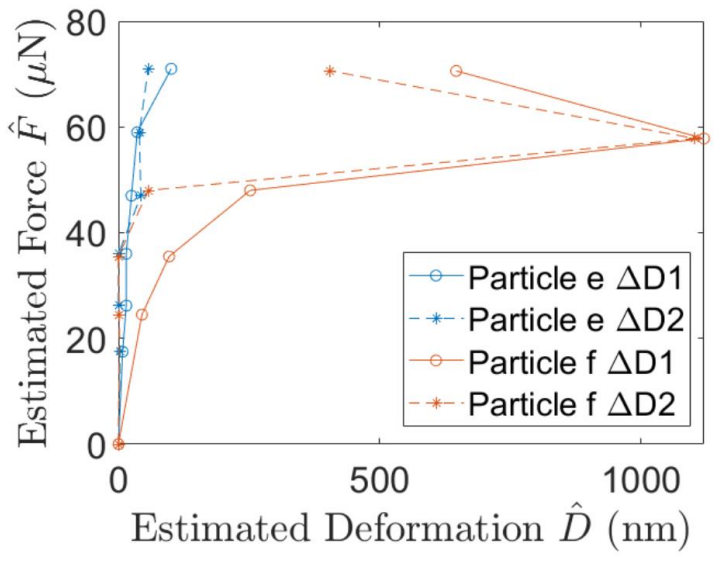
Vision algorithm and nano stage test

COMPARING THE DIFFERENT MATERIALS

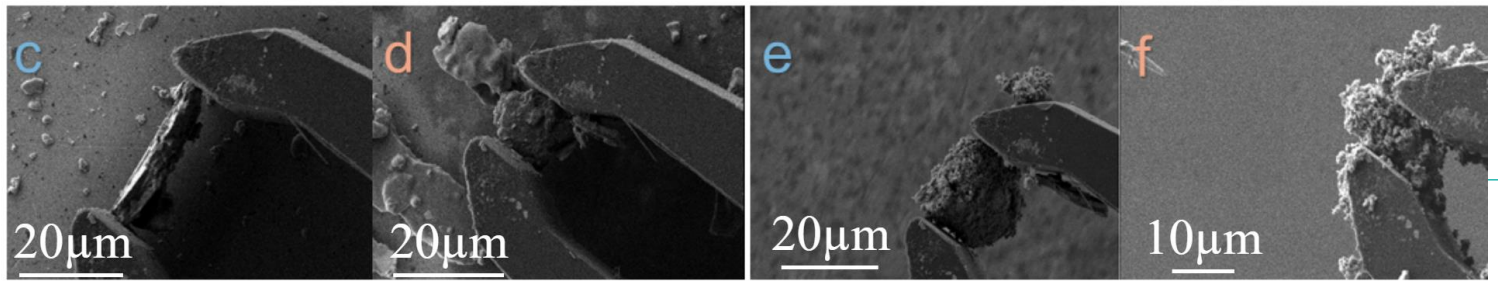




3ed Body pure MoS_2



3ed Body MoS_2+Ta

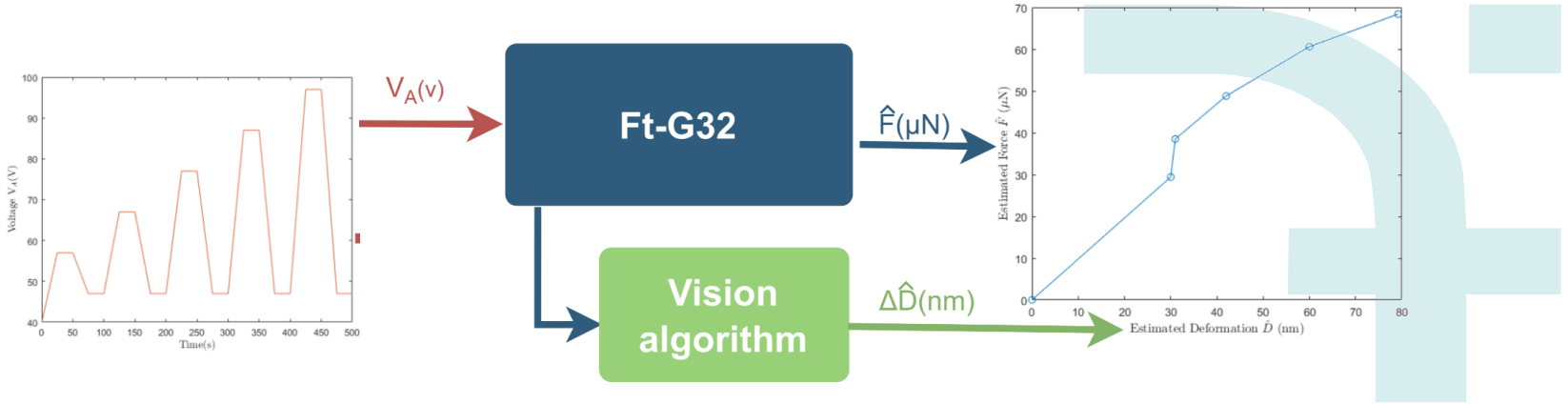


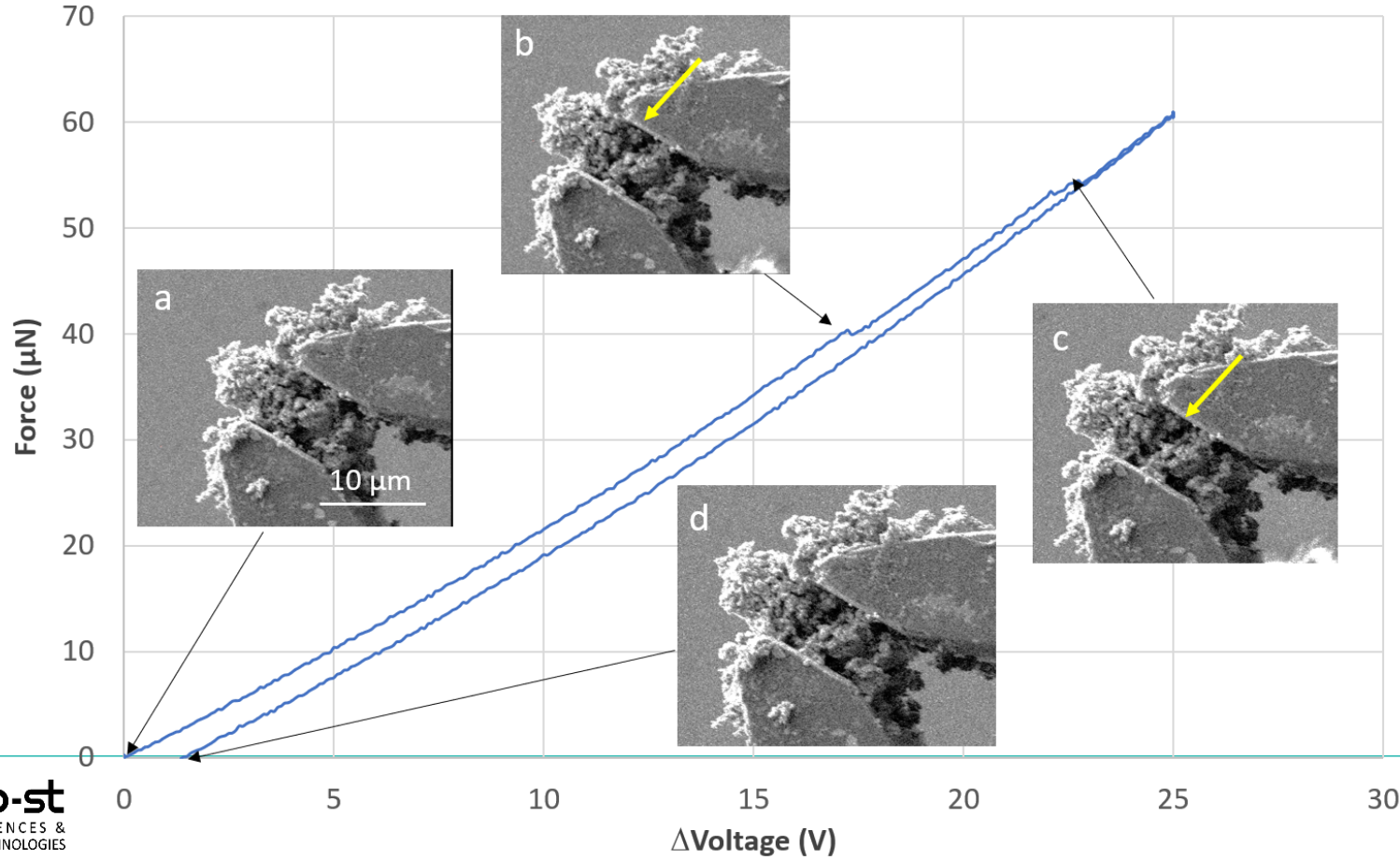
In the range of loading force

⇒ **MoS2 based particles is stiff and elastic**

⇒ **MoS2+Ta particles demonstrates different stiffness but always plasticity**

COMPARING THE DIFFERENT MATERIALS





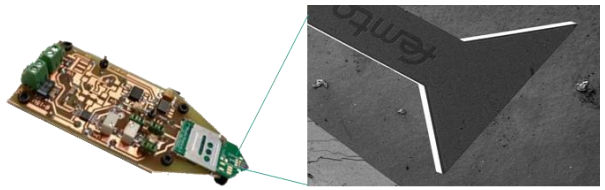
In the range of loading force

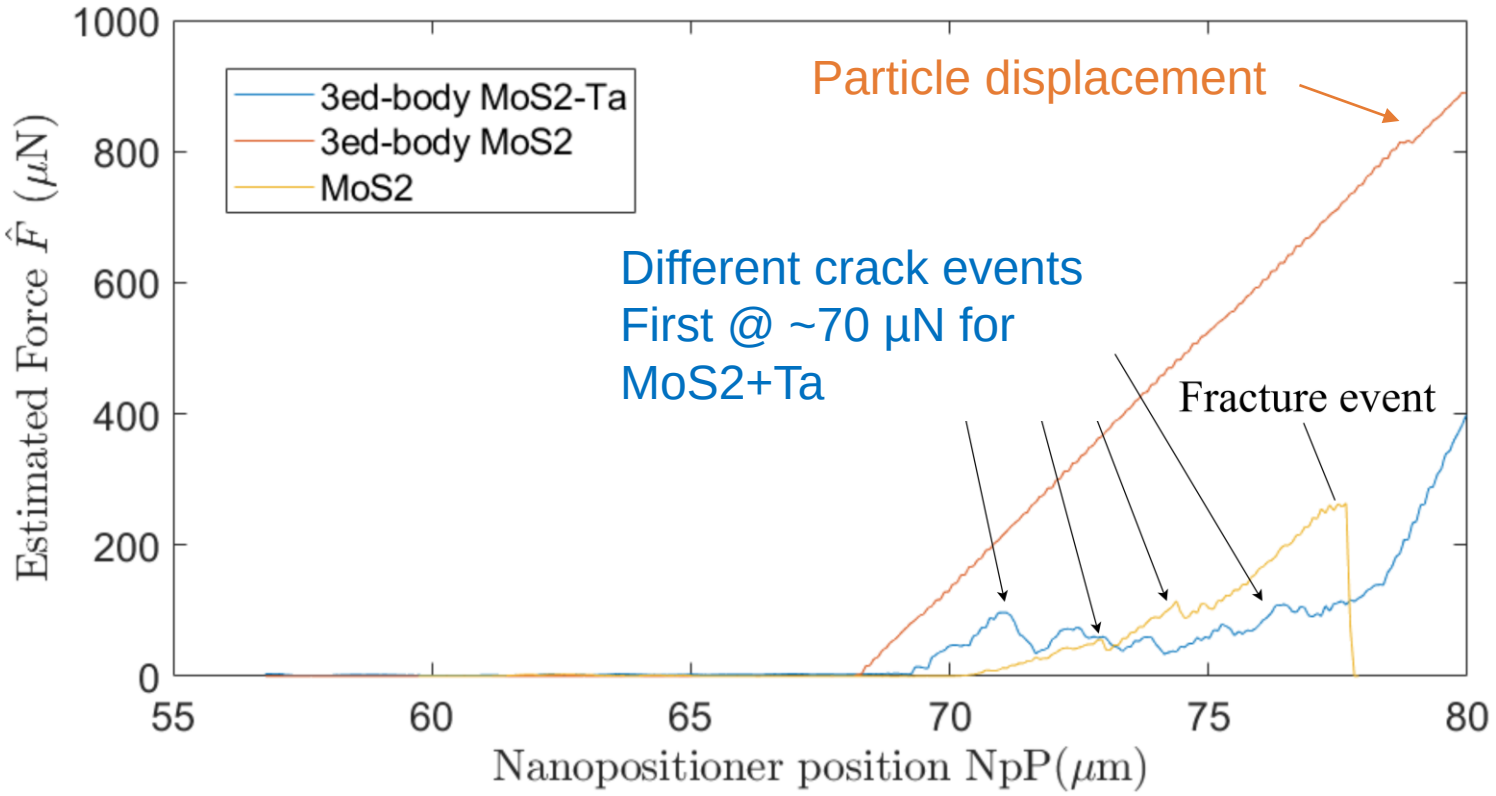
⇒ **MoS2 based particles is stiff and elastic**

⇒ **MoS2+Ta particles demonstrates different stiffness but always plasticity**

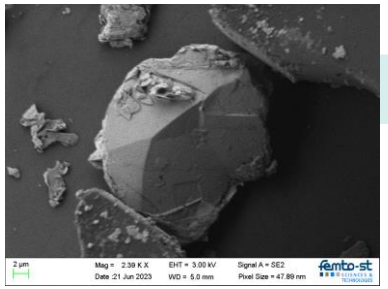
⇒ **Granular ; cracks and flows**

COMPARING THE DIFFERENT MATERIALS



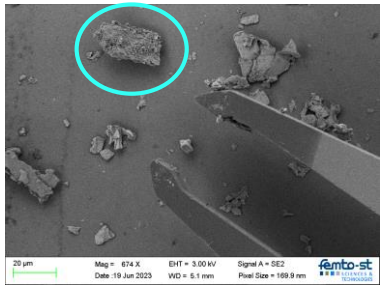


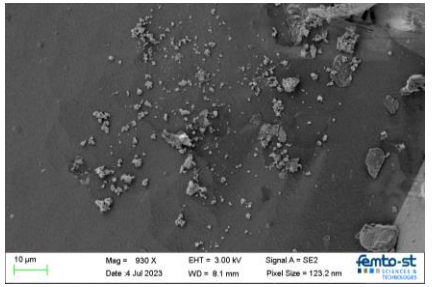
3rd body MoS_2 particle



Very high strength of the third body created from pure MoS_2.

3rd body MoS_2-Ta particle





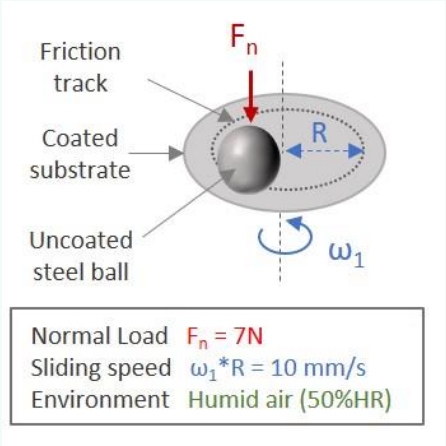
Cracks ; deformation ; destruction

- Fully consistent with microgripping experiments

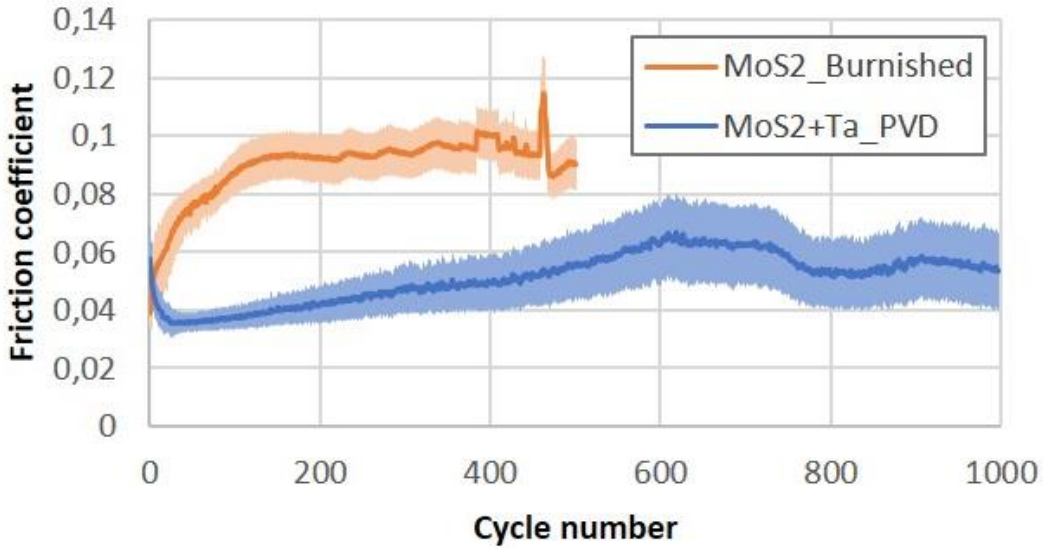
Conclusion

=> Surfaces coated with MoS2

Macroscale Friction tests



Micro-Nanoscale microgripper compression testing in-situ

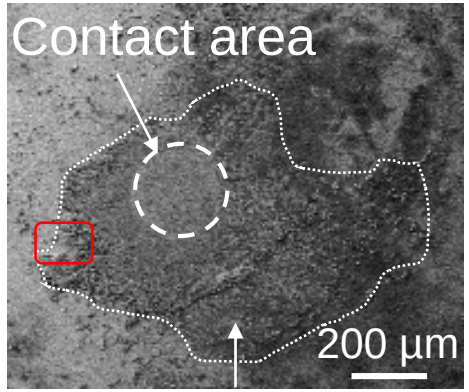


Particle…

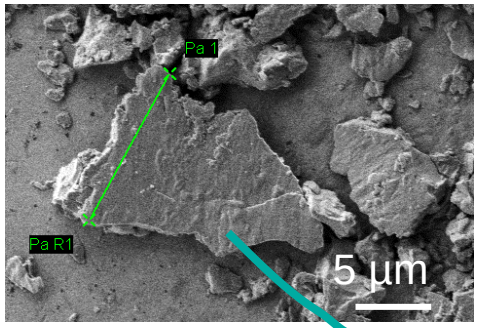
..stiff & brittle

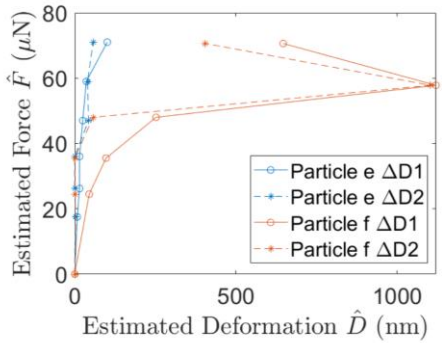
..soft & ductile

SEM analysis

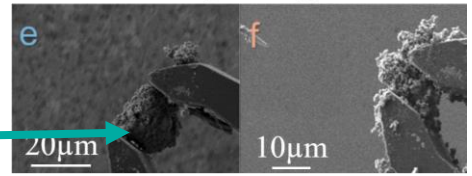


Ejected particles





3ed Body MoS_2+Ta



➢ Heading towards in situ quantitiative analysis

Conclusion

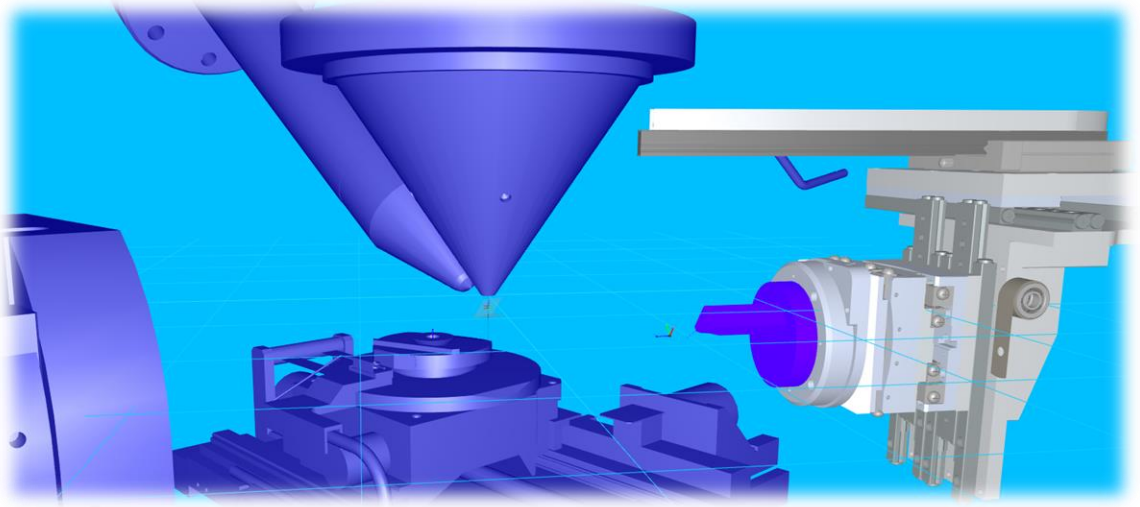
- Robotized system where tested and adapted to successfully work in-situ (SEM).

- Automated macro-scale movements and micro-analysis were successfully conducted.
- A teleoperated manipulation for fine micro-scale movement/gripping were successful.

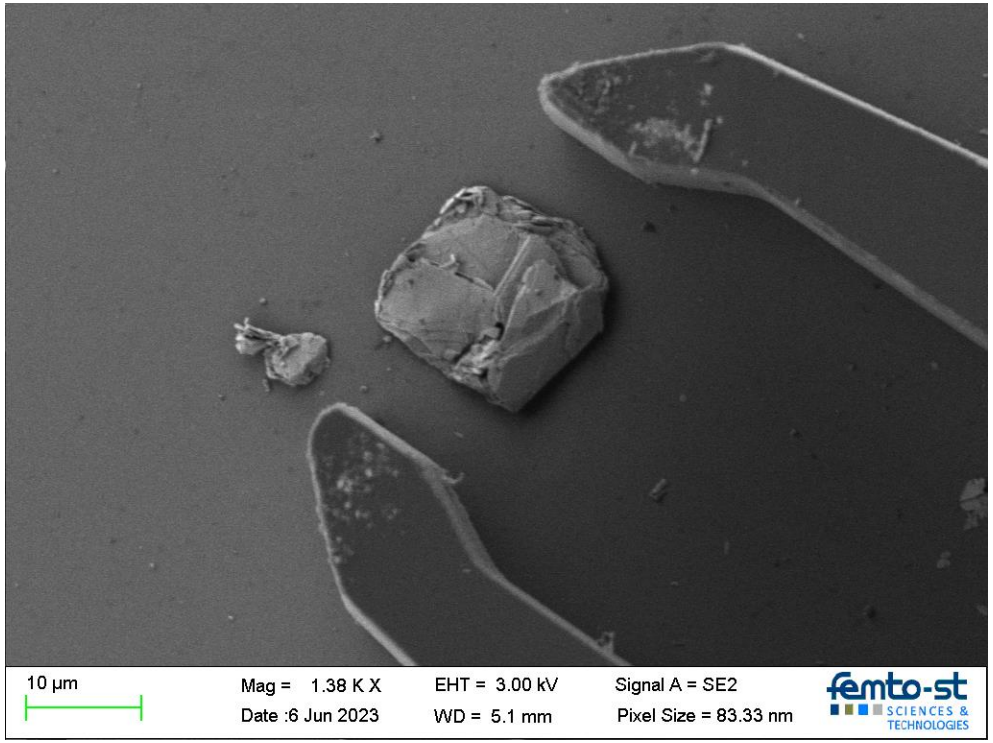
- The first semi-quantification and manipulation of the selected grains in the micro scale were successfully done in-situ (SEM environment).

Future perspective

Using the Digital Twin that could facilitate the safe and accurate positioning of the robotic systems in different scales, and fully automate the categorizing operation.



Thanks for your attention



Groupement de Recherche (GDR)
Caractérisation et mesures à l'échelle nanométrique
Janvier 2024

CarMA Nano

Objectifs du GDR :

- Établir un état des lieux des performances et des sources d'erreur des instruments
- Avancer vers la quantitativité des mesures
- Qualifier les mesures sur une échelle de maturité métrologique
- Croiser les compétences et créer du lien
- Coupler les instruments
- Développer et diffuser de nouvelles techniques de traitement des données
- Diffuser les bonnes pratiques

Animation et Contacts :

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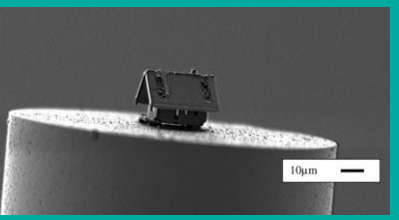
in-situ SEM Robotic-based Selection, Manipulation and Characterization of 3D Microscale Particles

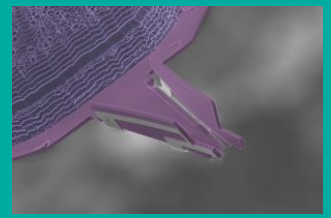
R. Hannouch, G. Colas, J-Y. Rauch, V. Reynaud, J. Agnus, O. Lehmann, F. Marionnet and C. Clévy

Cédric Clévy, Professor, FEMTO-ST, Franche-Comté University

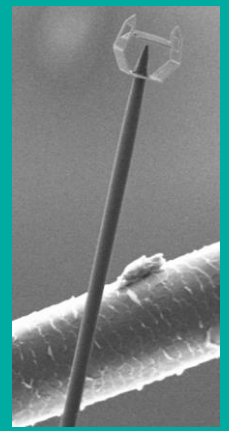


[J. Vac. Sc. 2018]

[Opt. Cont. 2022]



[Adv. Mat.. 2021]



[RA-L. 2021]

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