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Hard Self-lubricating Nanocomposite PVD Coatings for Space and Terrestrial Applications

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Outlook

1. Why using solid lubrication in space?
2. Introduction to solid lubrication with MoS_2
3. MoS_2 PVD thin films – specific problems
4. MoS_2 + hard phase: possible combinations
5. Experimental
6. MoS_2 + hard phase: mixed coatings
    1. Structure
    2. Tribology
7. Concluding remarks

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Why using solid lubrication in space?

Because:

1. Wide variations in temerature in space - fluid lubricants change viscosity, freeze, evaporate, crack.
2. Significant radiation (UV, gamma, etc.) – fluid lubricants change chemistry.
3. Vacuum – fluid lubricants evaporate.

Introduction to solid lubrication with MoS_2

Hexagonal, layered structure

Stacking sequence of layers:

: S : Mo : S : S : Mo : S :

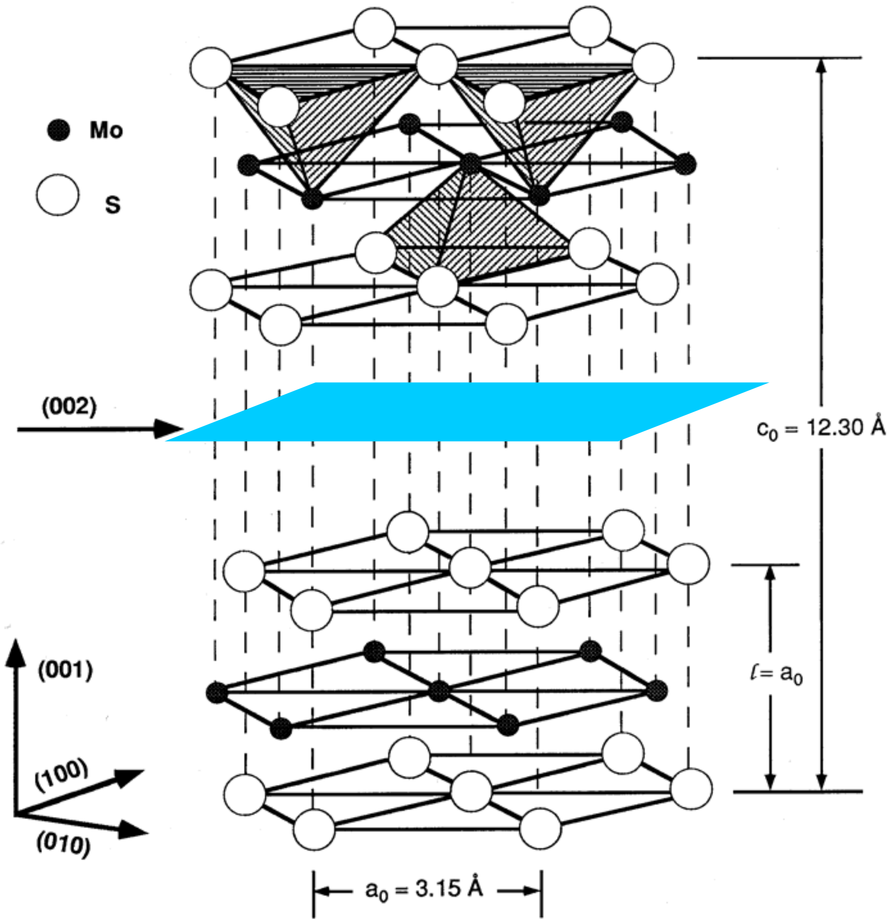
Bonding:

S : Mo : S **covalent bonding** (relatively strong)

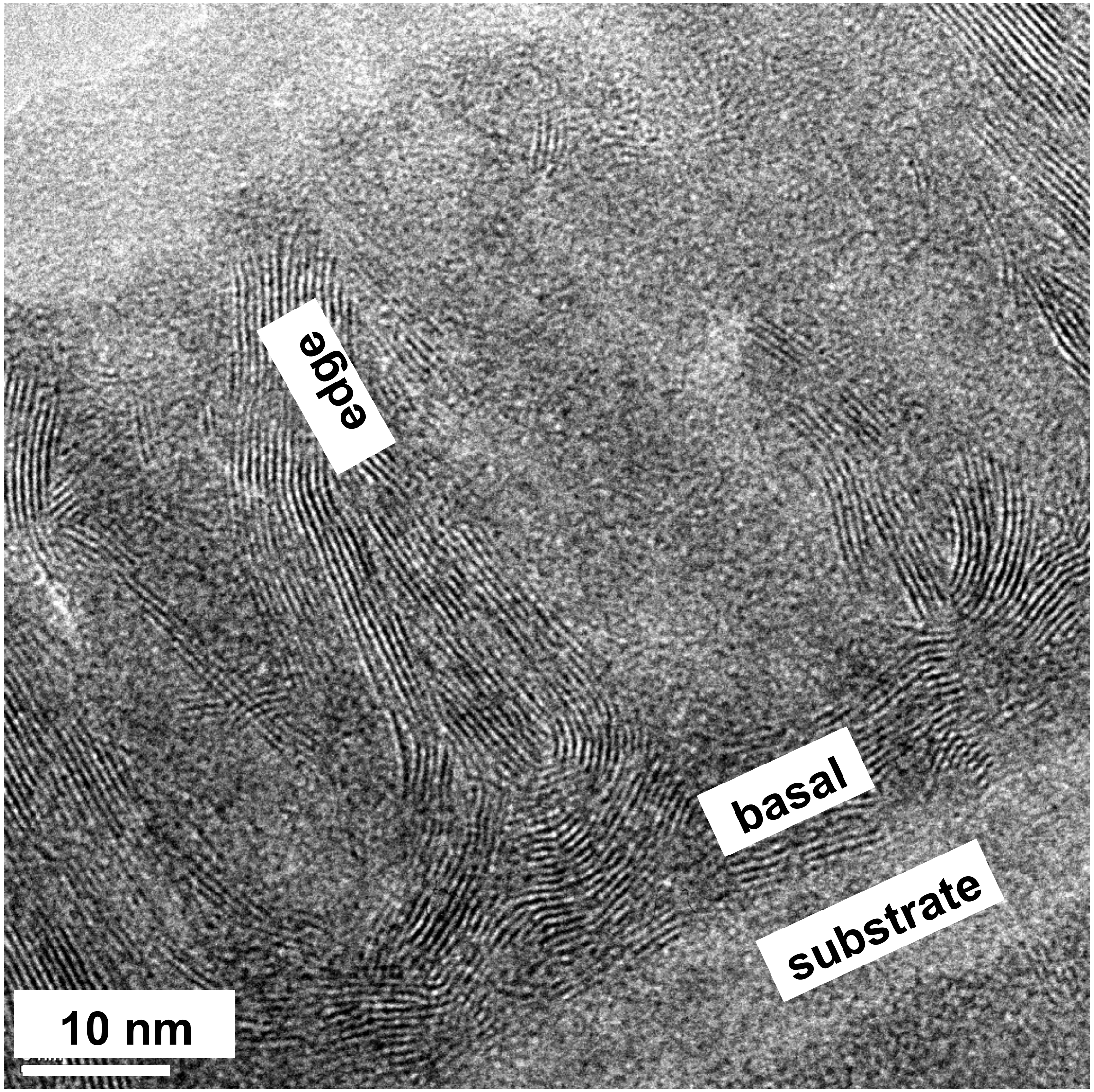
S : S **van der Waals bonding** (weakest bonding holding solids together)

Therefore the adjacent planes of S can slide easily over each other.

(002)



MoS_x PVD thin films – specific problems



Problem 1. Orientation of the (002) planes

Basal – good tribological properties

Edge – bad tribological properties

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MoS_x PVD thin films – specific problems

Problem 2. **Adhesion due to the presense of the (002) planes**

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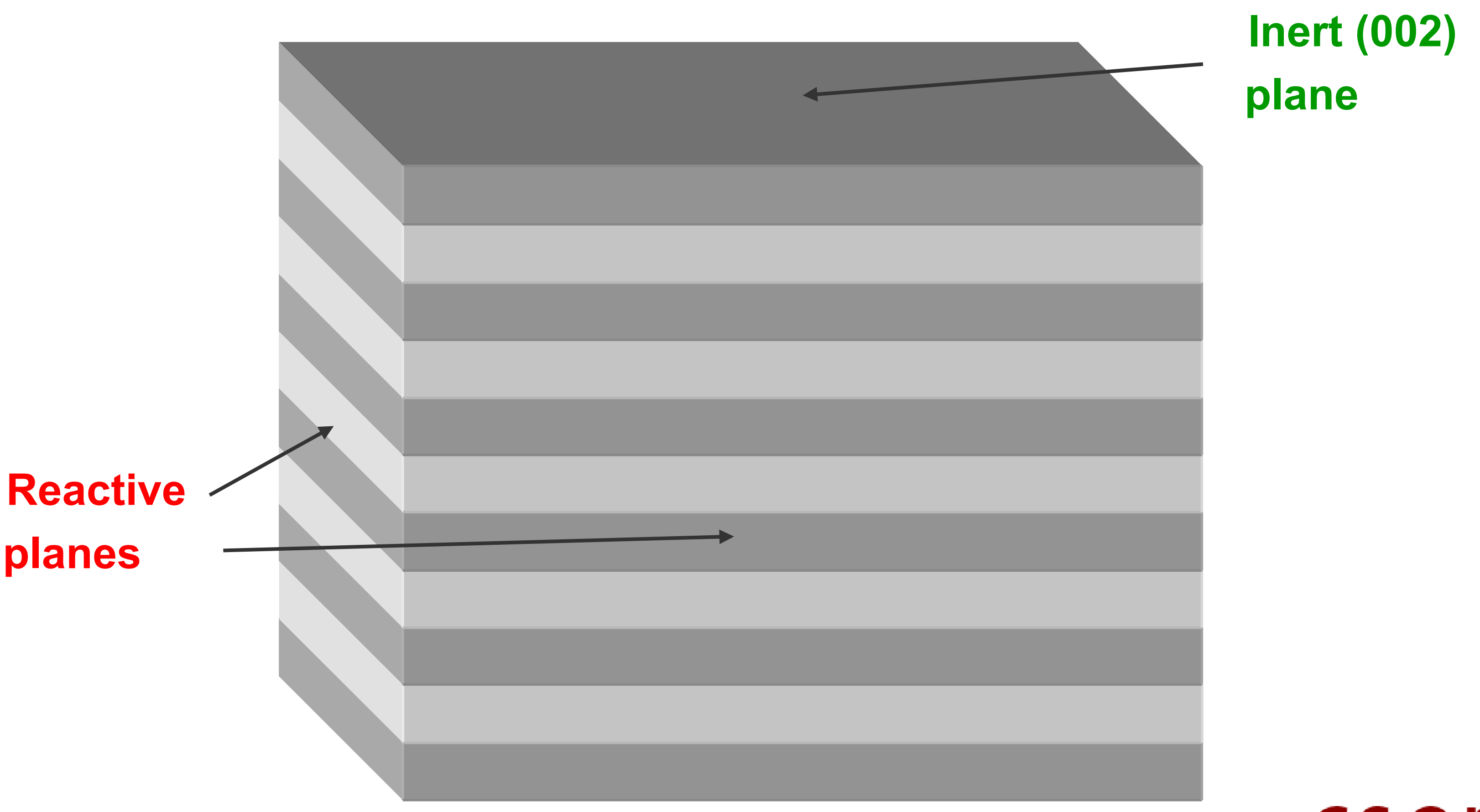
MoS_x PVD thin films – specific problems

Problem 3. **Oxidation at the edges of the (002) planes**

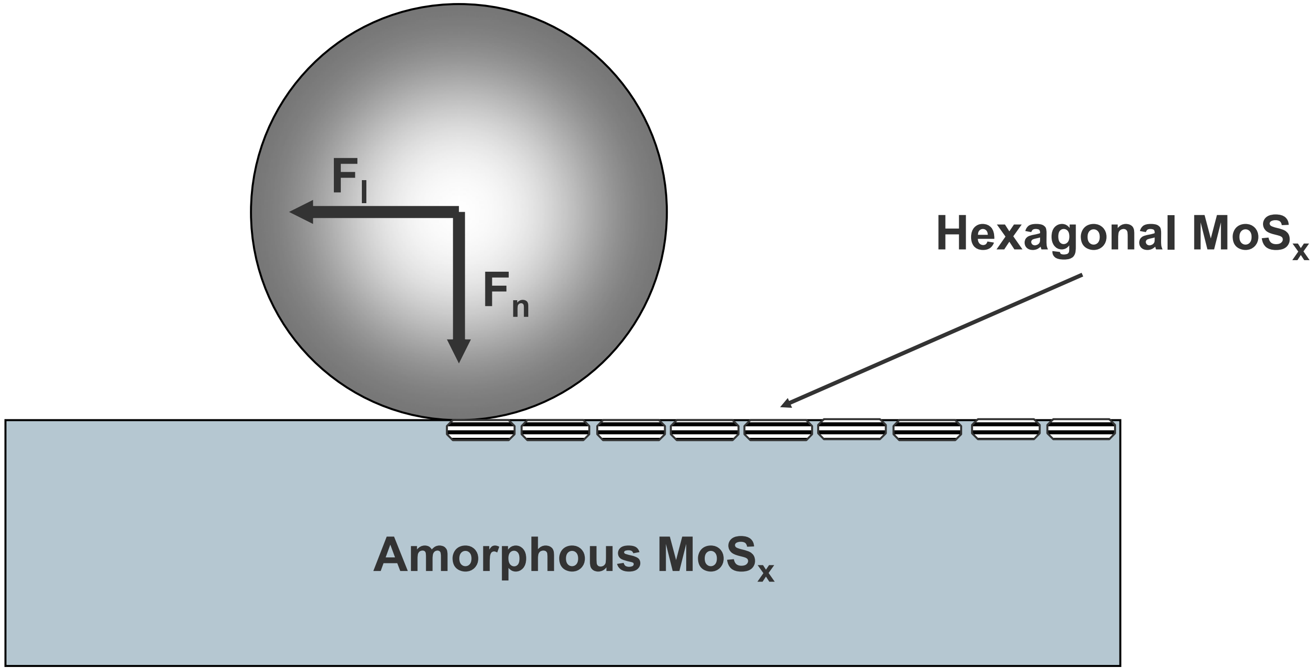
$2MoS_2 + 7O_2 \rightarrow 2MoO_3 + 4SO_2$; $2MoS_2 + 4H_2O + O_2 \rightarrow 2MoO_3 + 4H_2S$



MoS_x PVD thin films – specific problems

Solution: minimisation of the existence of (002) planes, especially edge ones by:

1. **Deposition at conditions allowing only basal crystallisation**
2. **Alloying MoS_2 with metals and compounds (amorphisation)**



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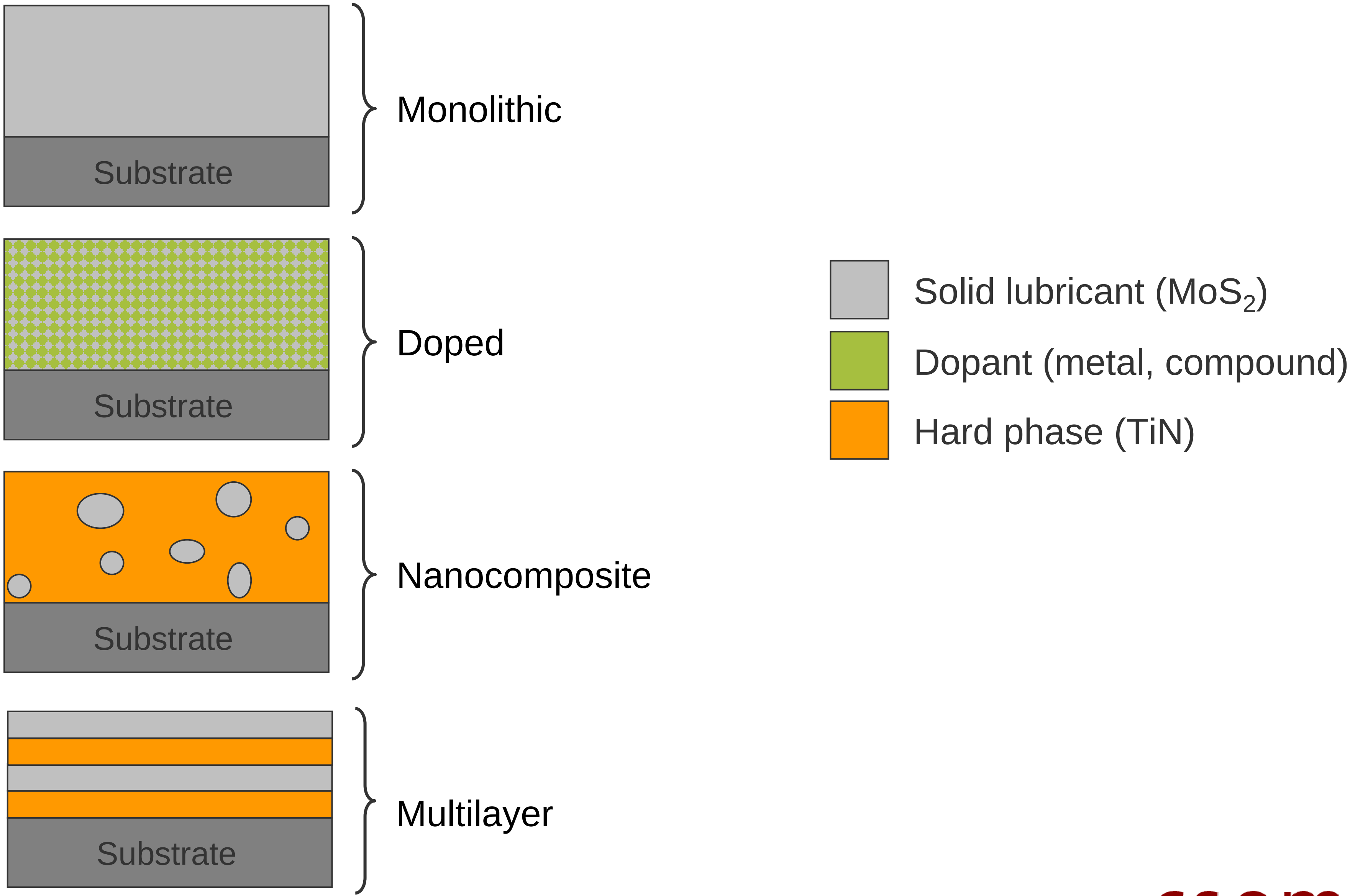
MoS_x + hard phase: possible combinations



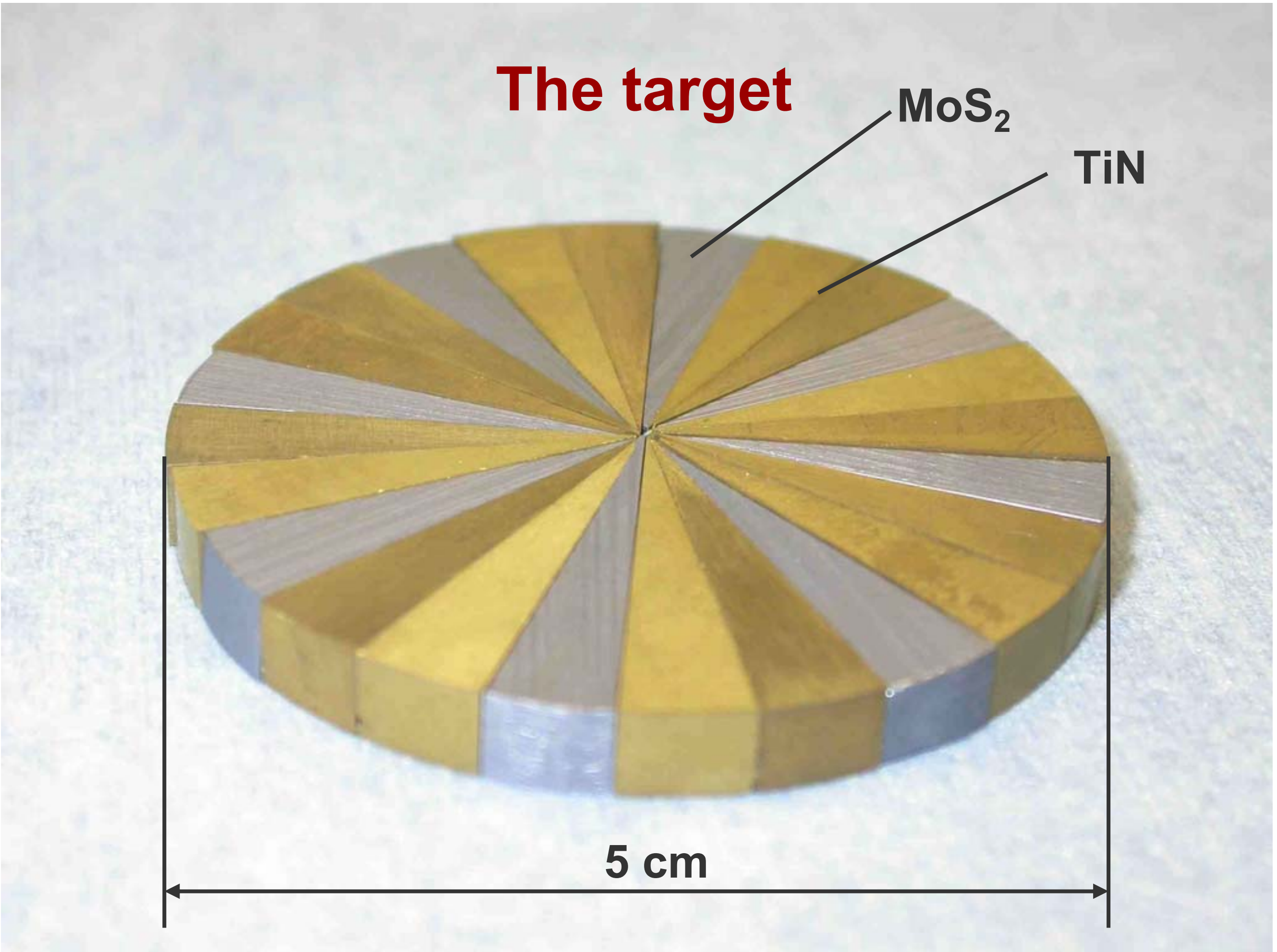
Experimental

Method for deposition: UnBallanced Magnetron (UBM) Radio Frequency (RF) non-reactive sputtering

Methods for investigation:

- **Structure and chemistry:** 200 kV Transmission Electron Microscope (TEM) equipped with Energy Dispersive X-ray (EDX) spectrometer
- **Tribological characteristics:** rotational Pin-On-Disk (POD) tribometer
- **Hardness:** Nano Hardness Tester (NHT)
- **Adhesion:** Micro Scratch Tester (MST)

Experimental



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MoS_2 + hard phase: mixed coatings: structure

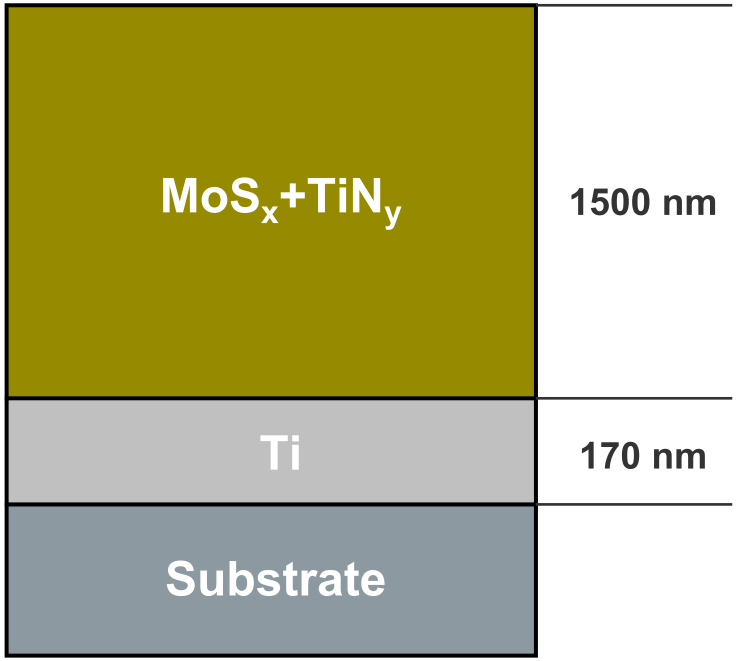
Deposition conditions:

Substrate bias: grounded

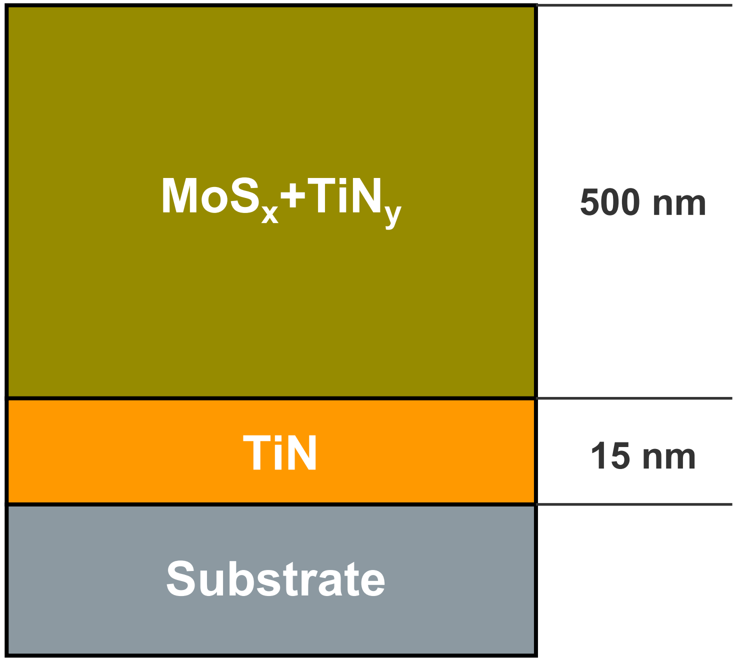
Temperature = 280 ºC

Pressure = 0.4 Pa

MoS_2 segments	Mo	S	(TiN_y)	MoS_x mol.%
2	14	20	66	17.5
3	17	34	49	25.8
4	25	38	37	40.3
5	25	46	29	46.3
6	30	48	23	56.6
8	28	54	18	60.9



For tribology and TEM



For TEM (multilayers)

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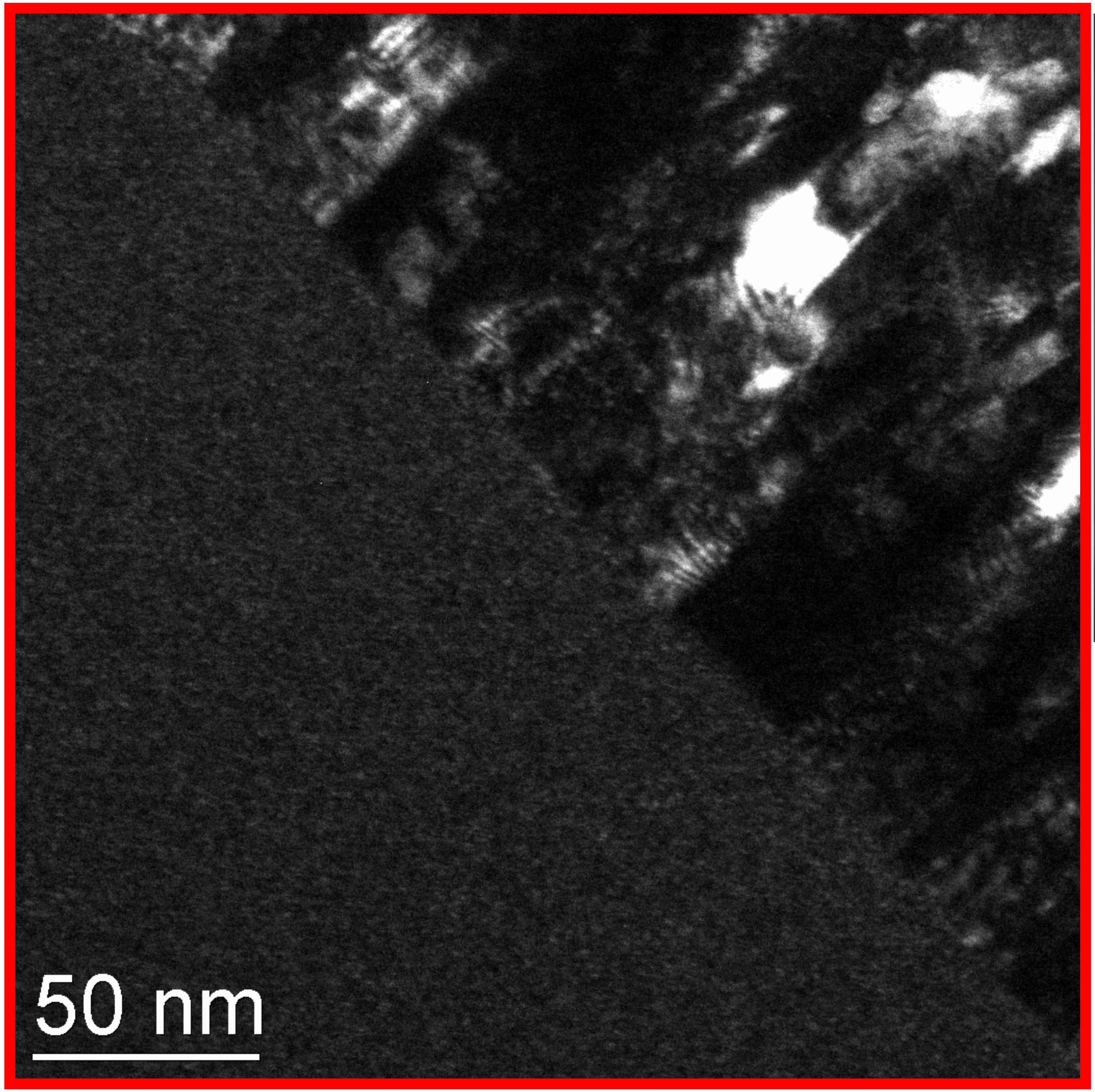
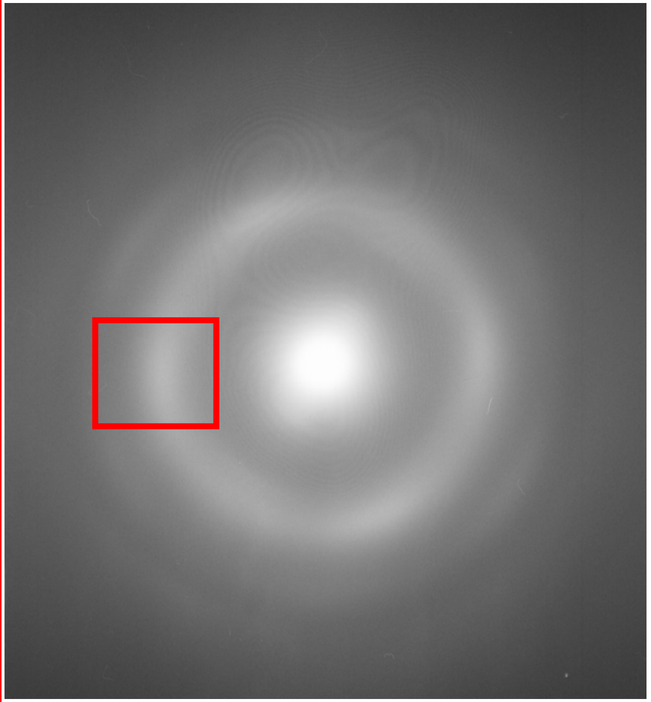
MoS_2 + hard phase: mixed coatings: structure





MoS_x 60.9 mol.%

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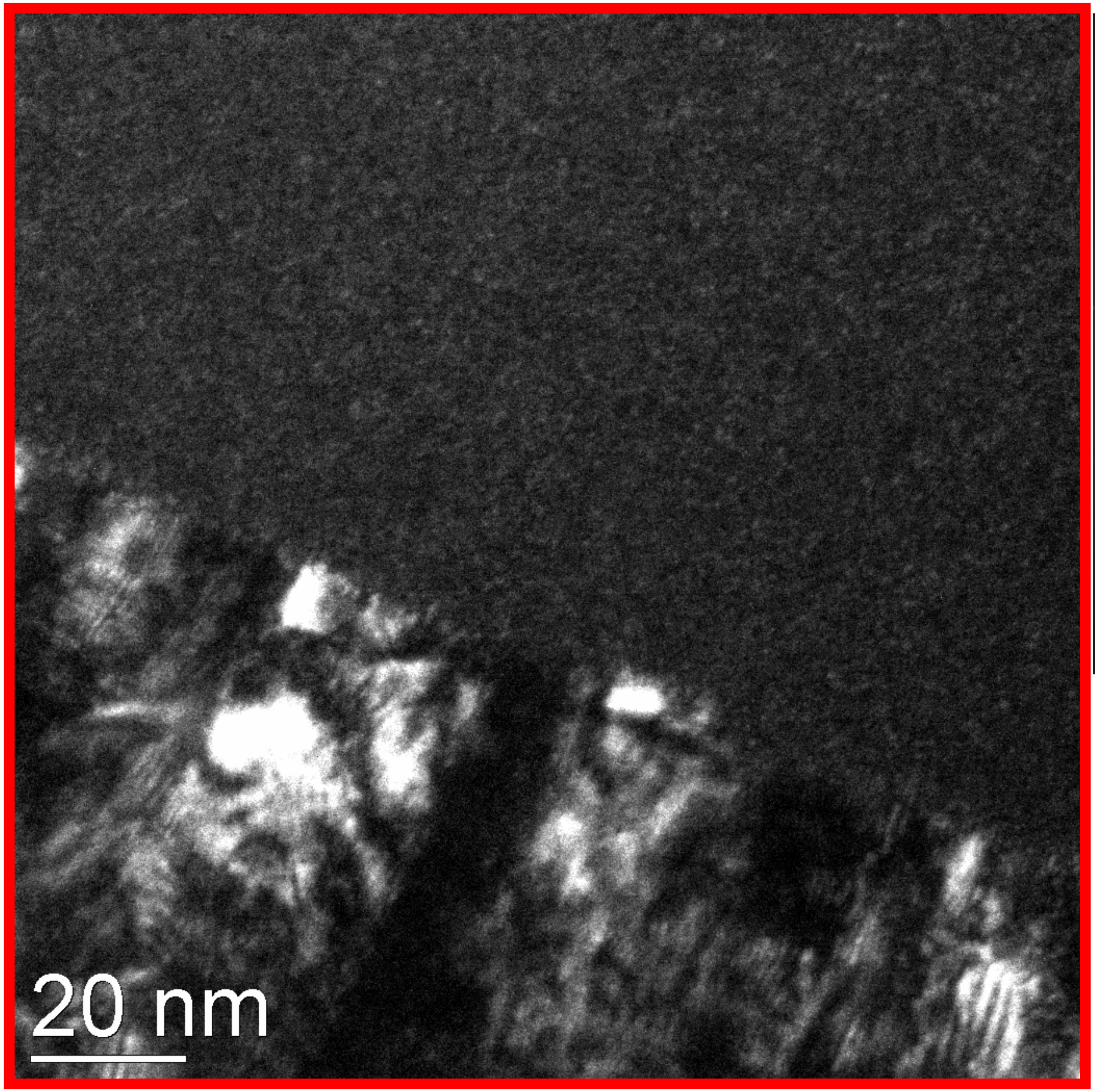
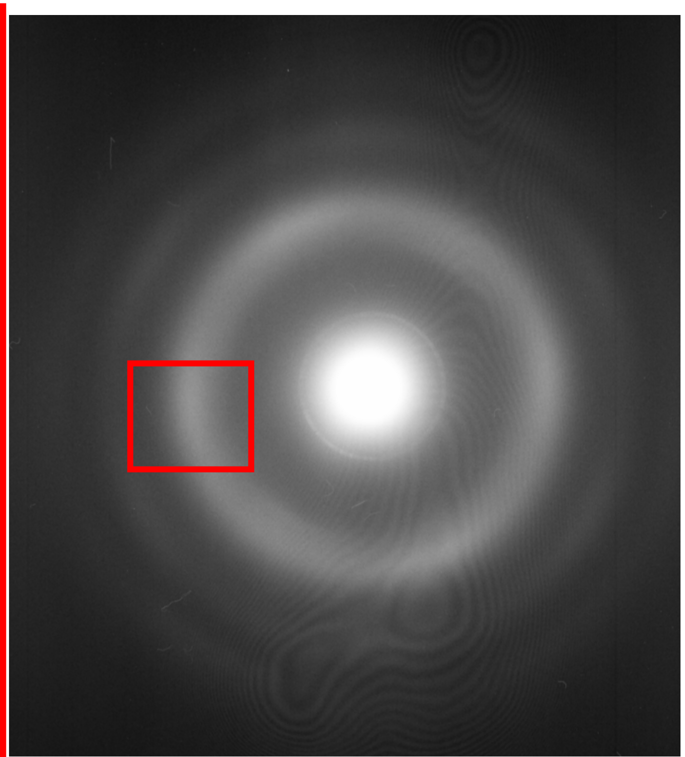
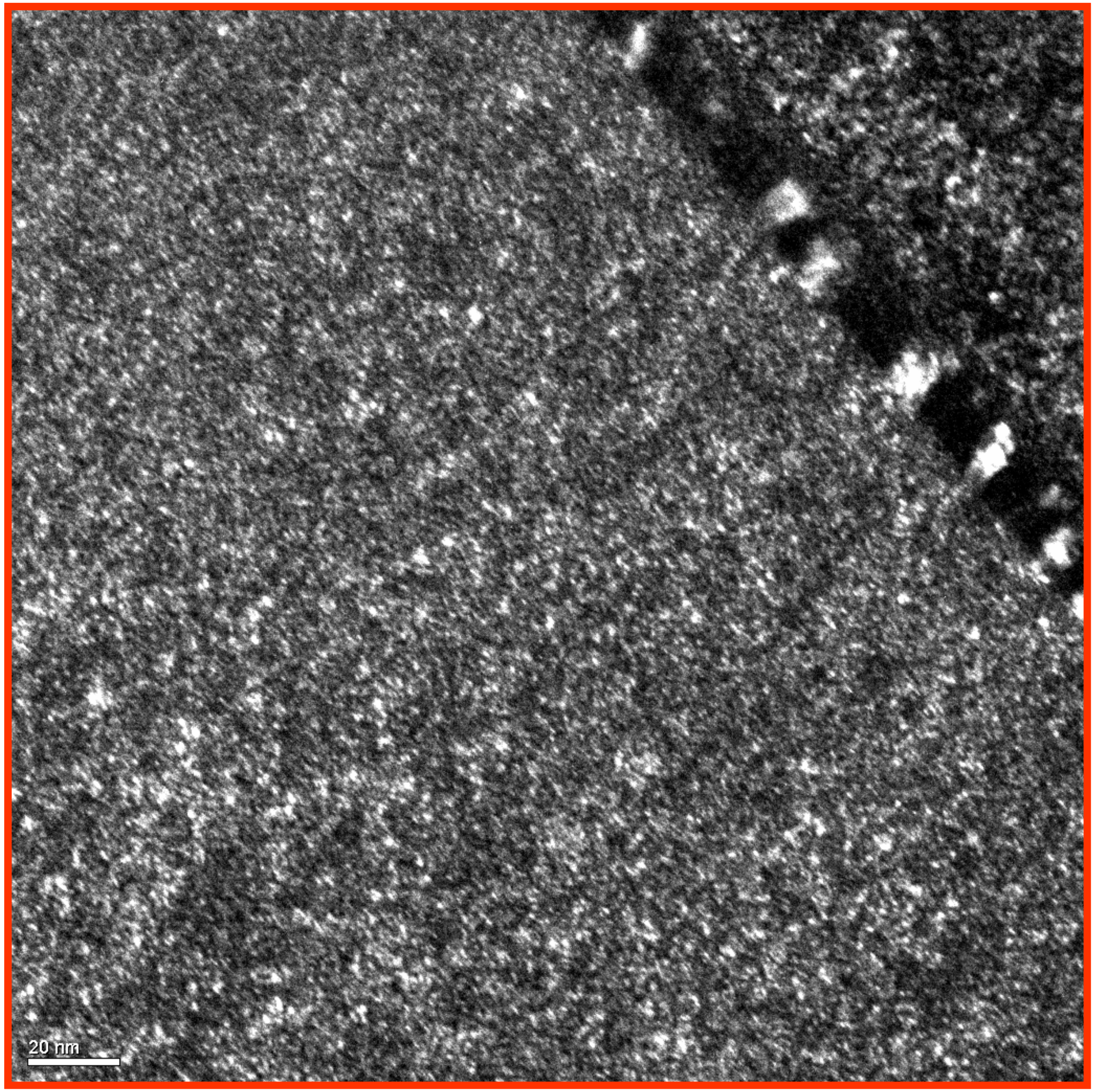
MoS_2 + hard phase: mixed coatings: structure

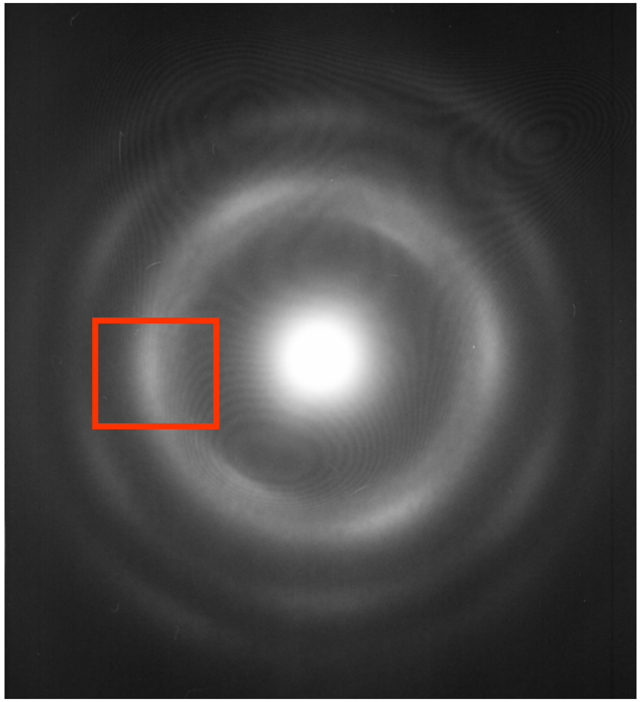




MoS_x 56.6 mol.%

MoS_2 + hard phase: mixed coatings: structure





MoS_x 46.3 mol.%

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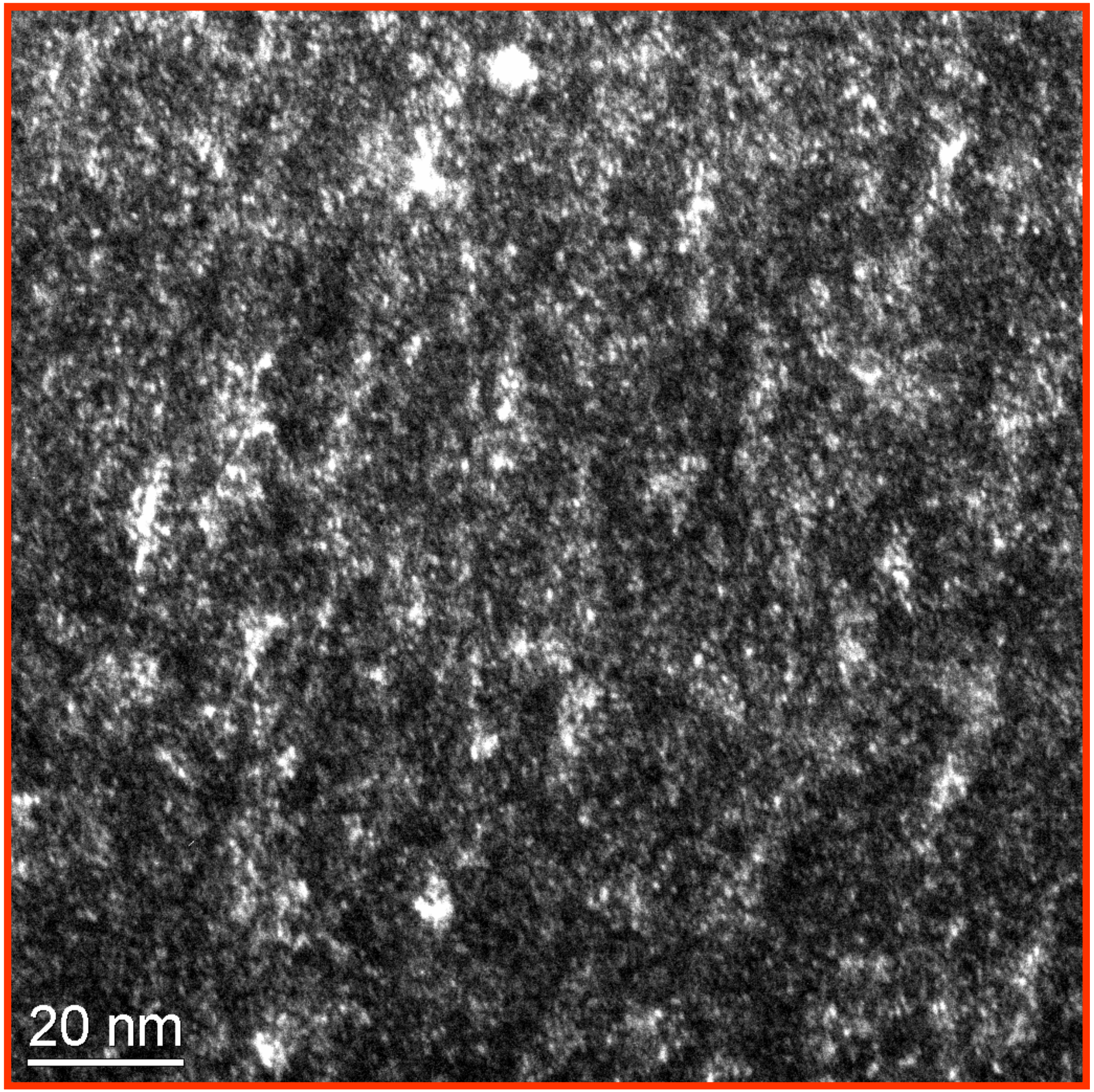
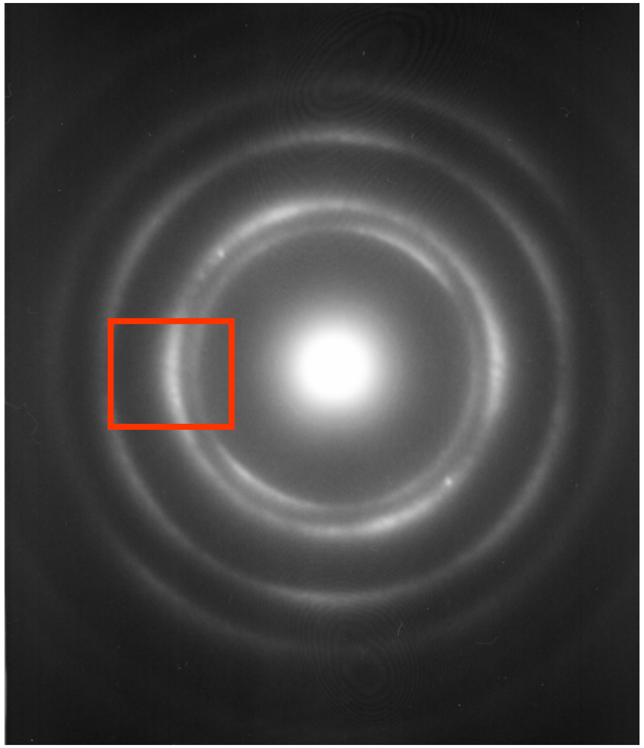
MoS_2 + hard phase: mixed coatings: structure





MoS_x 40.3 mol.%

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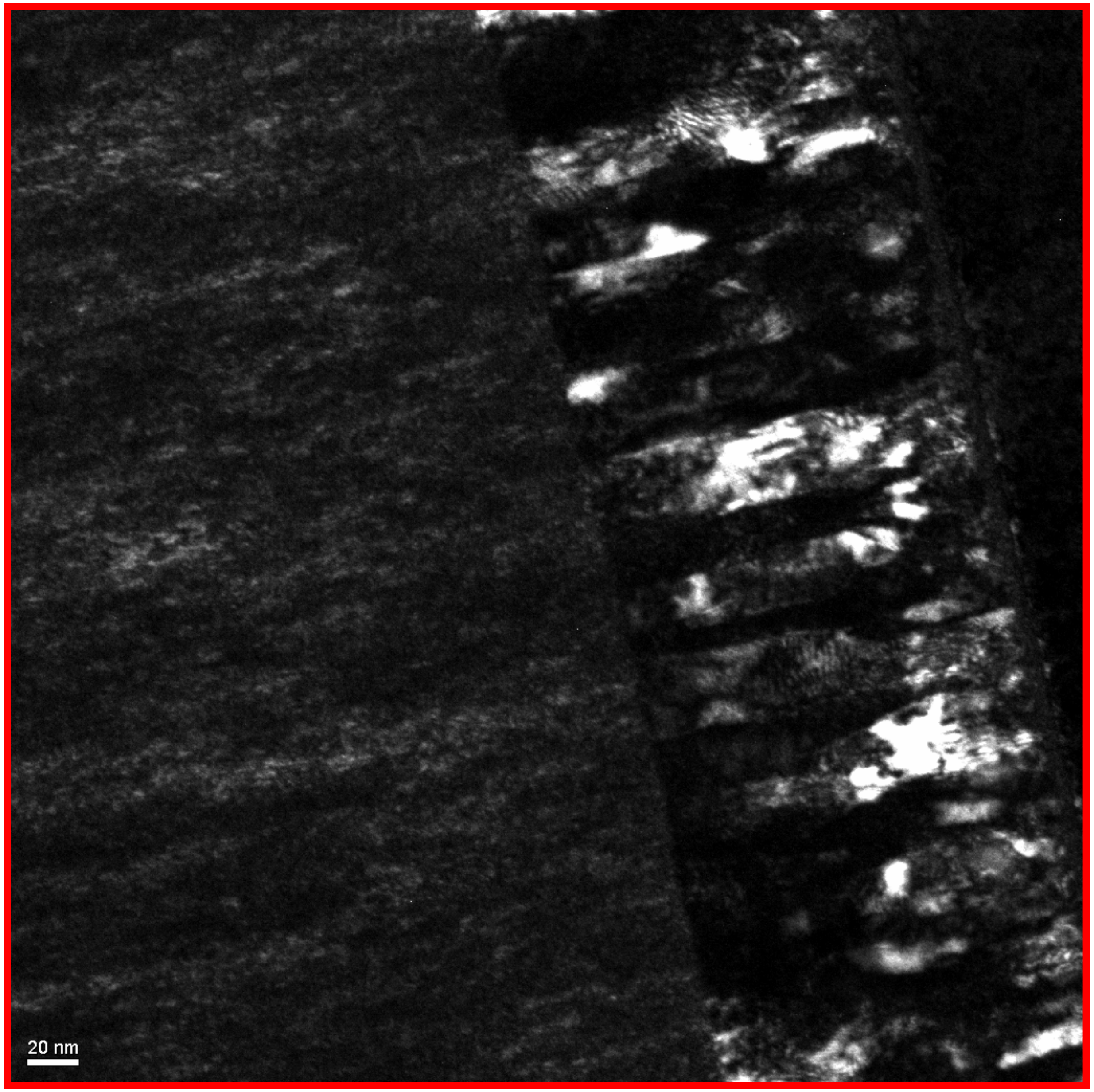
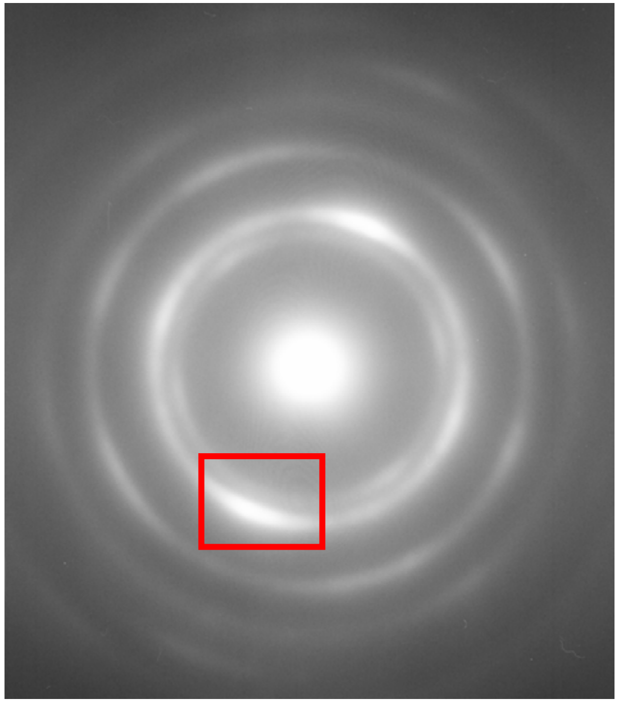
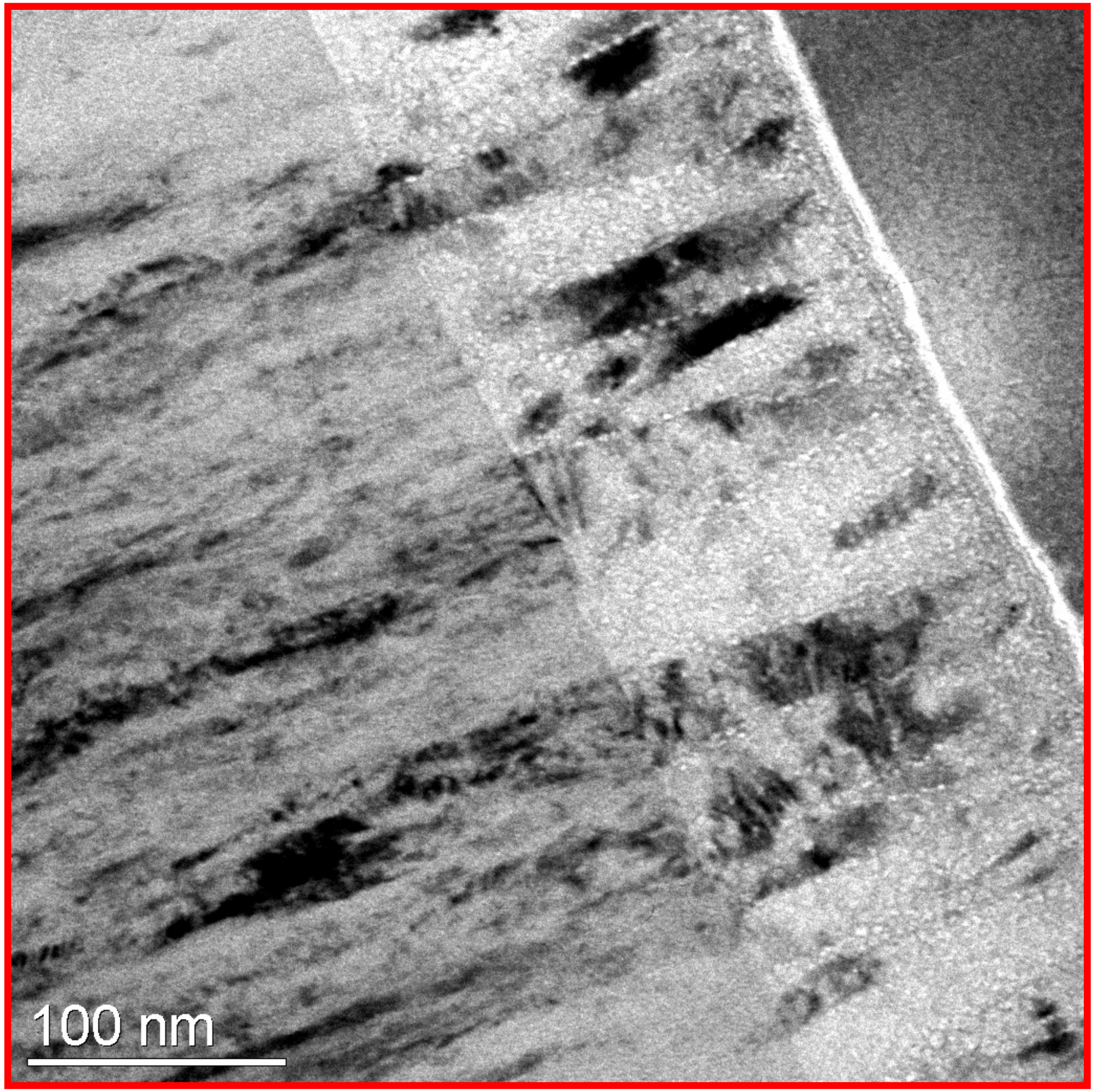
MoS_2 + hard phase: mixed coatings: structure

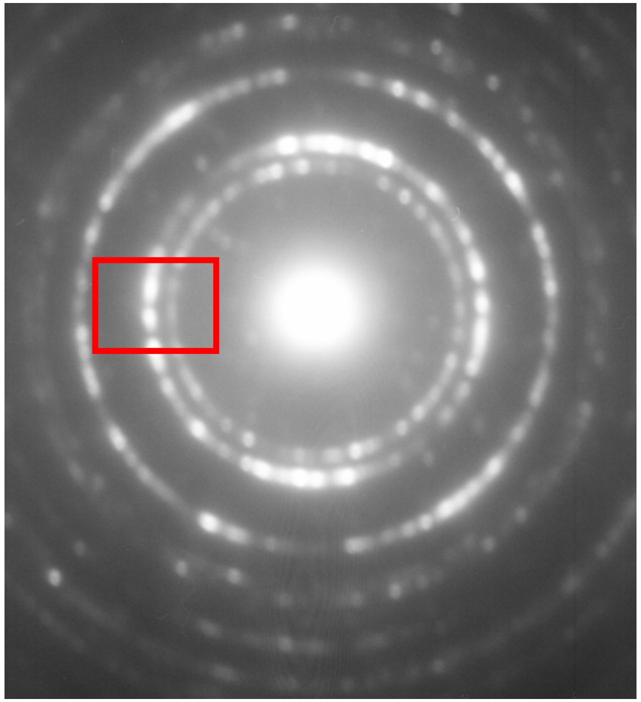




MoS_x 25.8 mol.%

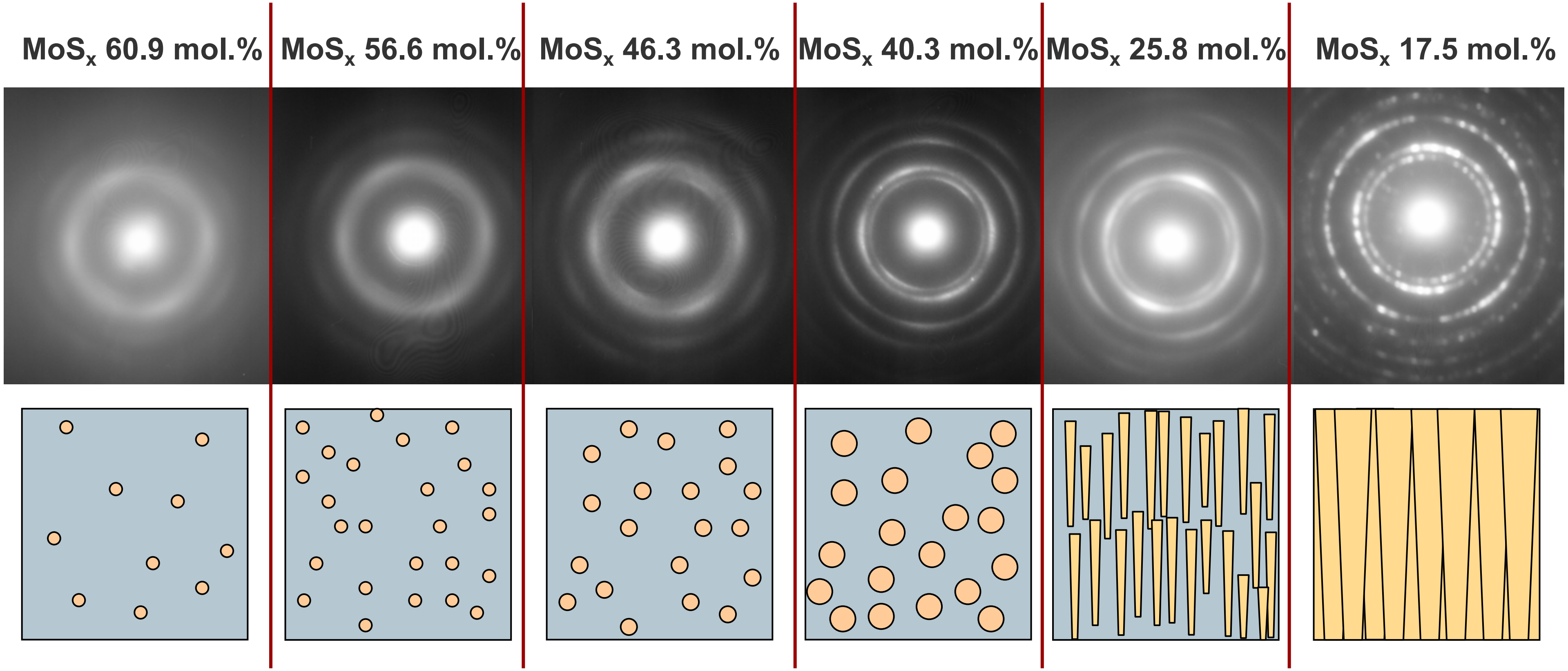
MoS_2 + hard phase: mixed coatings: structure





MoS_x 17.5 mol.%

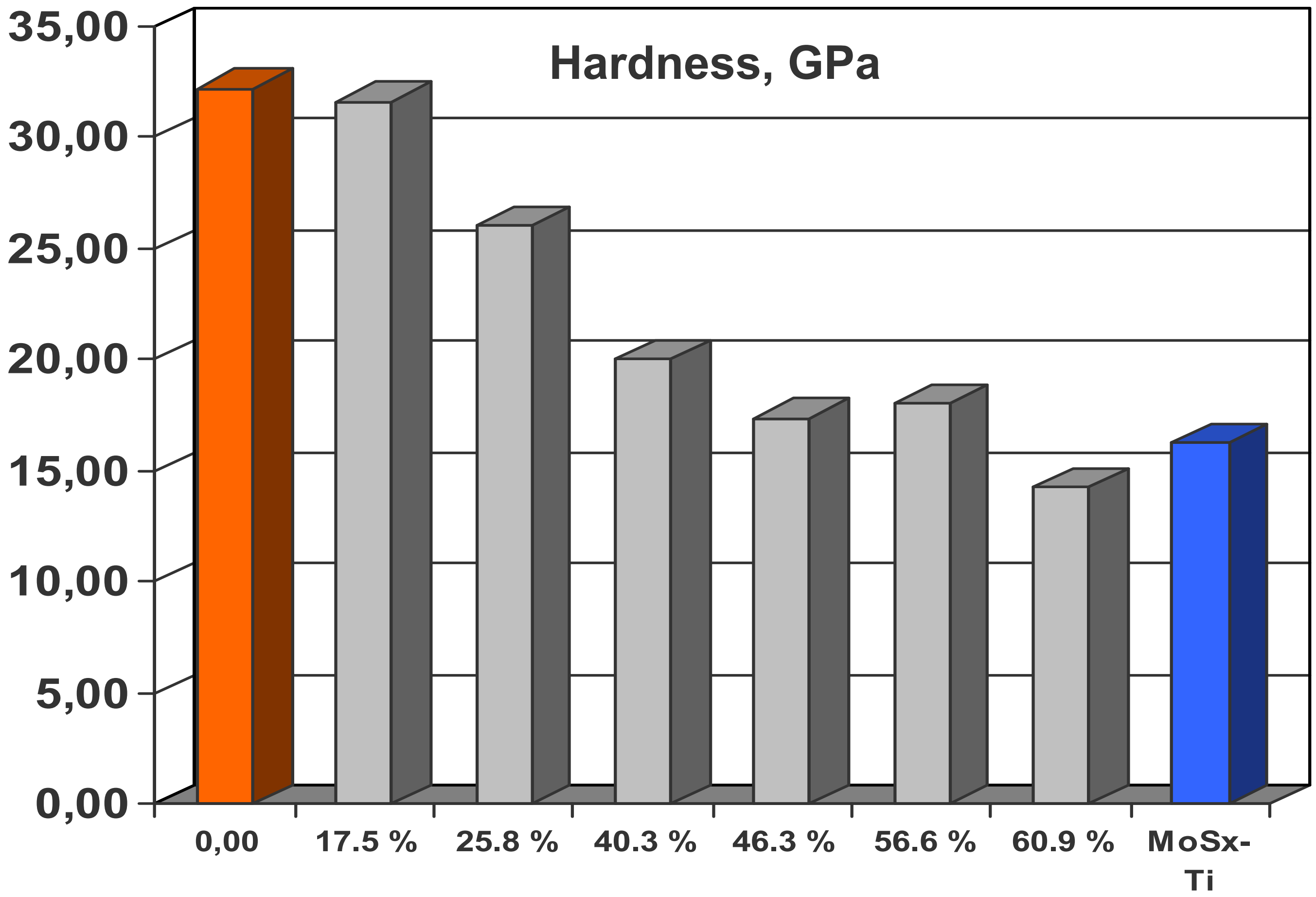
MoS_2 + hard phase: mixed coatings: structure



amorpous $MoS_xTi_yN_z$ solid solution

fcc-$Ti_vN_wMoS_u$ solid solution

MoS_2 + hard phase: mixed coatings: tribology



Test conditions: **Berkovich indentor, 5 mN normal load, penetration depth 80 – 150 nm (< 10% of the coating thickness)**

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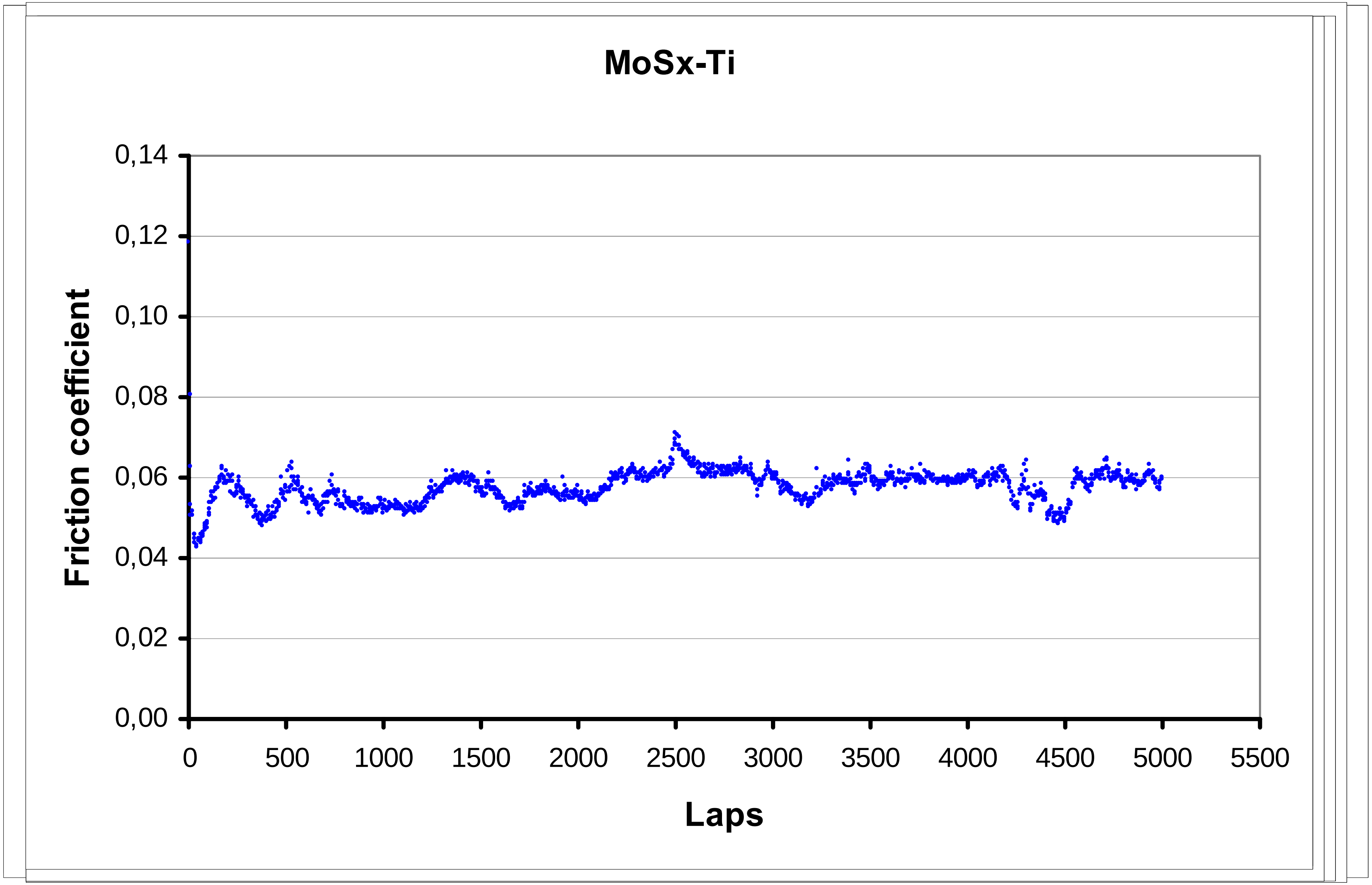
MoS_2 + hard phase: mixed coatings: tribology



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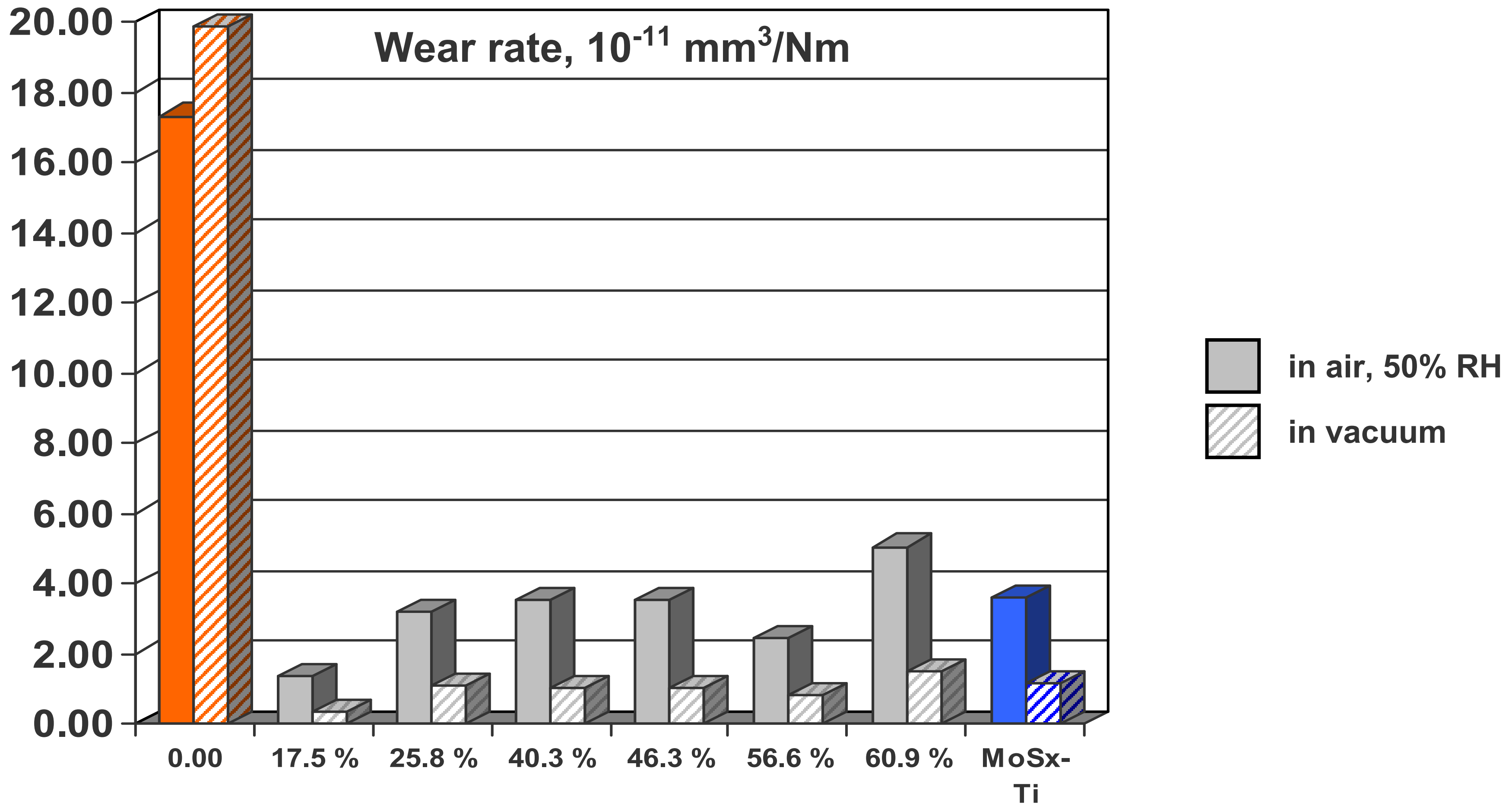
MoS_2 + hard phase: mixed coatings: tribology



Test conditions: ø 6 mm Al_2O_3 ball, normal load 5 N, sliding speed 0.1 m/s, radius 5 mm, temperature 24 ºC

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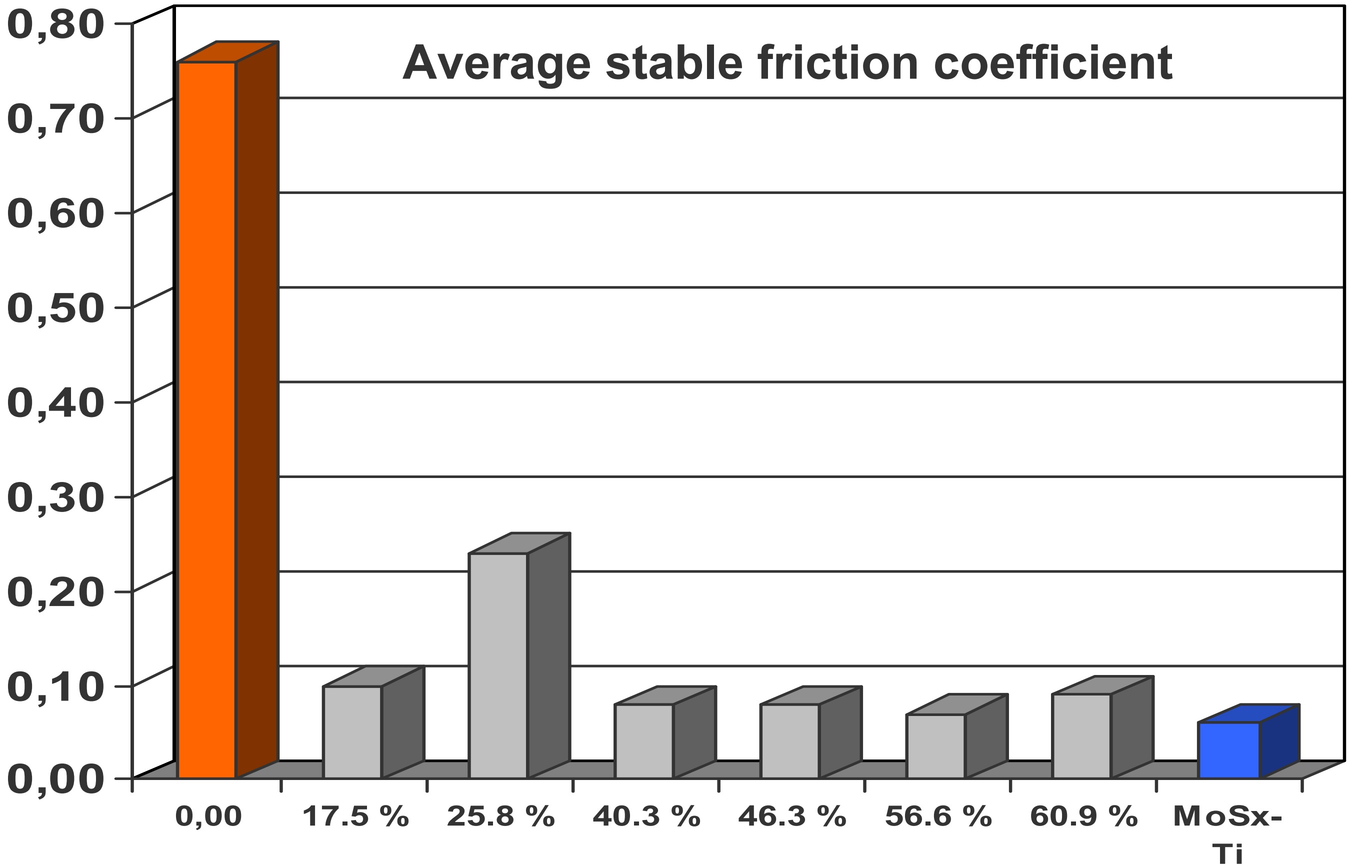
MoS_2 + hard phase: mixed coatings: tribology



Test conditions: ø 6 mm Al_2O_3 ball, normal load 5 N, sliding speed 0.1 m/s, radius 5 mm, temperature 24 ºC, 50 % RH

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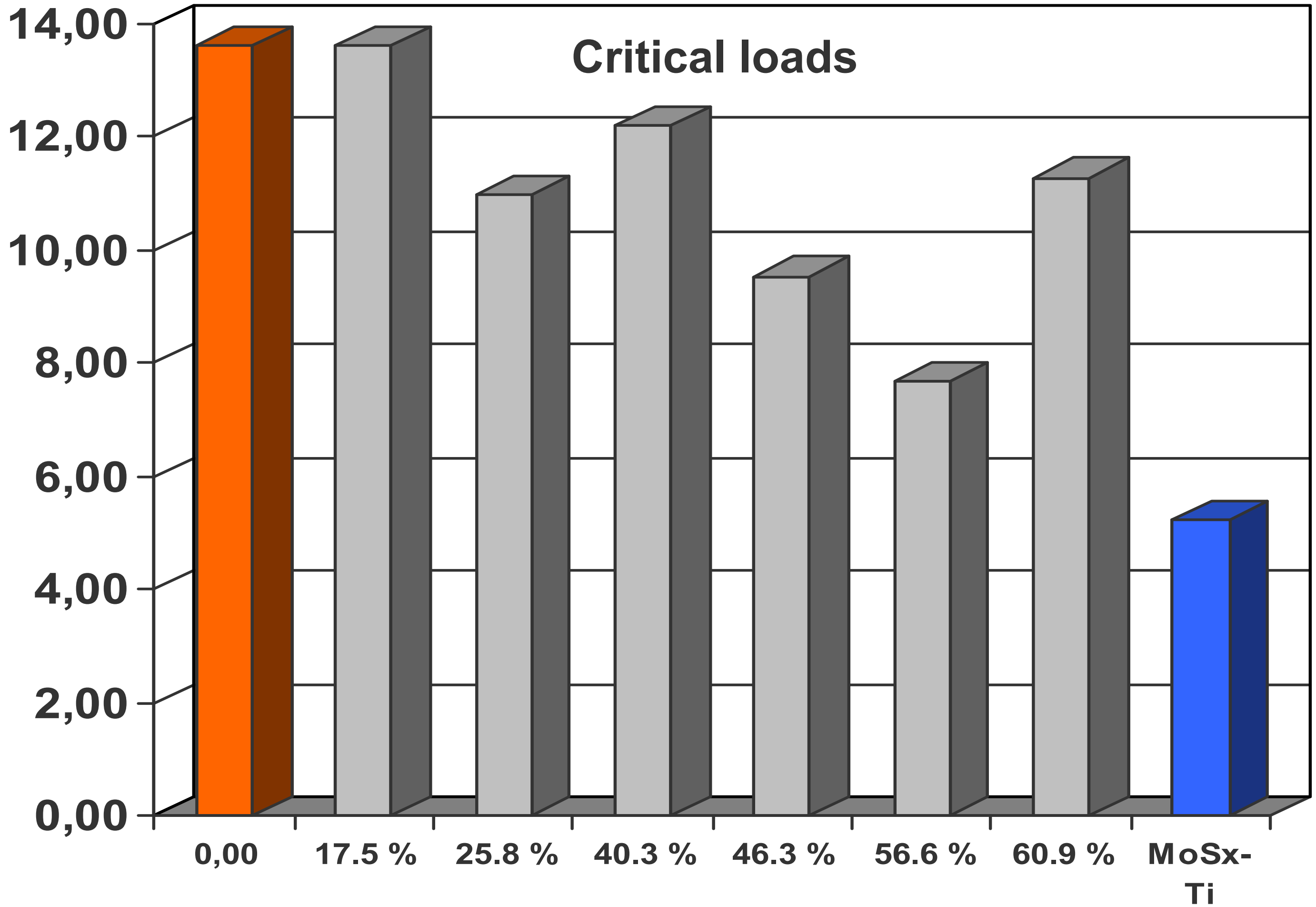
MoS_2 + hard phase: mixed coatings: tribology



Test conditions: Progressive scratch, Rockwell diamond indentor, 200 µ tip radius, initial load 0.1 N, final load 30 N, loading rate 100 N/min, sliding speed 10 mm/min

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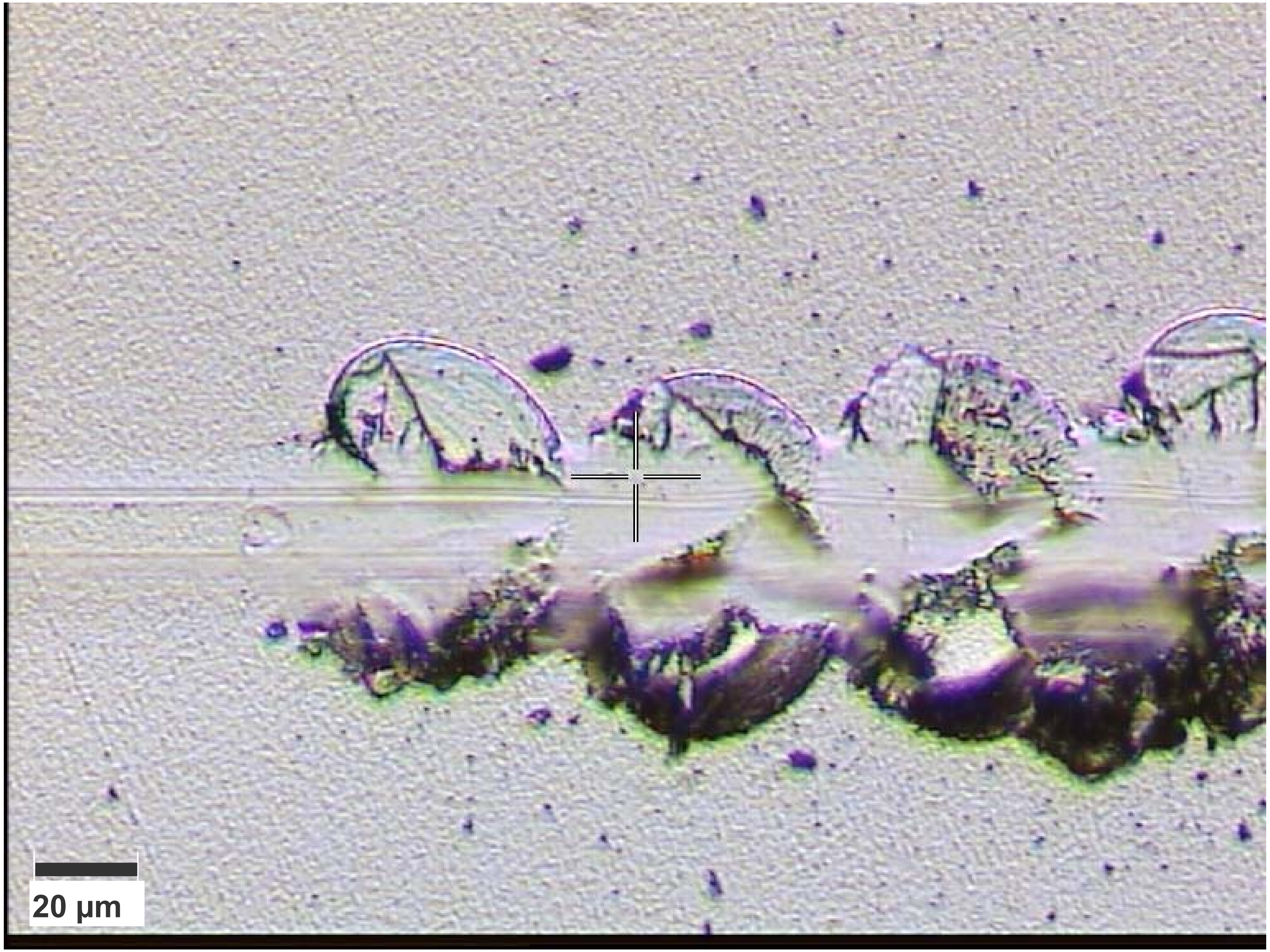
MoS_2 + hard phase: mixed coatings: tribology

Critical loads defined as cohesive/adhesive spallation



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Concluding remarks

- Alloying TiN with MoS_x changes the structure of the TiN from dense columnar to nanocrystalline. There is a treshold of MoS_x content below which all the MoS_x is dissolved in the fcc TiN matrix and the structure becomes dense columnar.
- Alloying TiN with MoS_x results in coatings with good adherence to the substrate, low friction coefficient and wear rate against alumina counterpart of up to an order of magnitude lower than that of pure TiN. The lowest wear rate is avhieved for the minimum MoS_x content, being 17.5 mol.%. The hardness of this coating is the same as for the pure TiN.
- The resulting coatings show very promising tribological properties in both high vavuum and Earth atmospheric conditions.

Thank you for your attention.