

Description of Additional Supplementary Files

File Name: Supplementary Movie 1

Description: LSMO (001) surface in 0.5 Pa H₂O. Observation of a high Mn adatom mobility on flat A-terminated (001) surfaces due to partial solvation in H₂O. Frame rate is 4.4 fps.

File Name: Supplementary Movie 2

Description: LSMO (001) surface with a step in 0.5 Pa H₂O. Observation of a reduced Mn adatom mobility due to Ehrlich-Schwöbel barrier at a step edge on the (001) surface. Frame rate is 4.4 fps.

File Name: Supplementary Movie 3

Description: LSMO (001) surface in high vacuum (10⁻⁵ Pa). Observation of the (001) surface with mixed A- and B-termination shows a reduced Mn mobility compared to H₂O. Frame rate is 4.4 fps.

File Name: Supplementary Movie 4

Description: LSMO (001) surface in 100 Pa O₂. Highly ordered (001) A-terminated surface with a step edge and reduced adatom mobility compared to H₂O. Frame rate is 4.4 fps.

File Name: Supplementary Movie 5

Description: LSMO (001) surface in 10 Pa N₂. Ordered B-terminated (001) surface that shows a reduced Mn adatom mobility compared to H₂O. Frame rate is 4.4 fps.

File Name: Supplementary Movie 6

Description: PCMO (001) surface in 0.5 Pa H₂O. Ordered PCMO (001) surface that shows irreversible Mn dynamics with a pronounced leaching of Mn out of the surface and the formation of a Pr-rich bilayer. Frame rate is 4.4 fps.

File Name: Supplementary Movie 7

Description: PCMO surface close to (001) in high vacuum (10⁻⁵ Pa). Disordered PCMO surface close to (001) typically observed in high vacuum, where leaching of Mn is absent. Frame rate is 4.4 fps.

File Name: Supplementary Movie 8.

Description: PCMO surface in 100 Pa O₂. Highly ordered surface with (001) facets and mixed termination, where leaching of Mn is absent. Frame rate is 4.4 fps.

File Name: Supplementary Movie 9.

Description: Preparation of ordered LSMO (001) surfaces in 100 Pa O₂. Initial state of the LSMO surface after ion milling before recrystallization in O₂. Frame rate is 4.4 fps.

File Name: Supplementary Movie 10.

Description: Preparation of ordered LSMO (001) surfaces in 100 Pa O₂. Final state of surface recrystallization in O₂. Frame rate is 4.4 fps.