Atomic-Scale Characterization of Iron Oxide Thin Film on Ag(001) by Scanning Tunneling Microscopy

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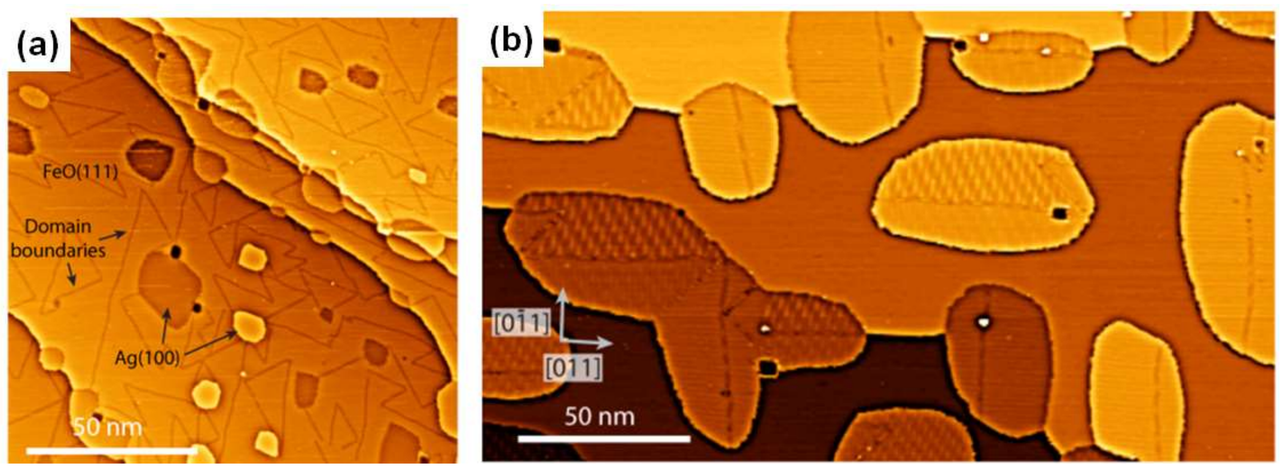
Abstract

High resolution scanning tunneling microscopy has been used to characterize the structural properties and growth mechanism of iron oxide thin film deposited on an Ag(001) substrate. Our experimental results show that the FeO(111) monolayer exhibits a c(2 × 10)/p(2 × 11)/c(2 × 12) unit cell due to lattice matching between the hexagonal overlayer and square substrate lattices. Besides, line defects with locally square atomic coordination are formed due to the excess oxygen in FeO thin film. Our findings provide a platform for understanding the metal oxide-substrate interactions down to atomic scale.

Introduction

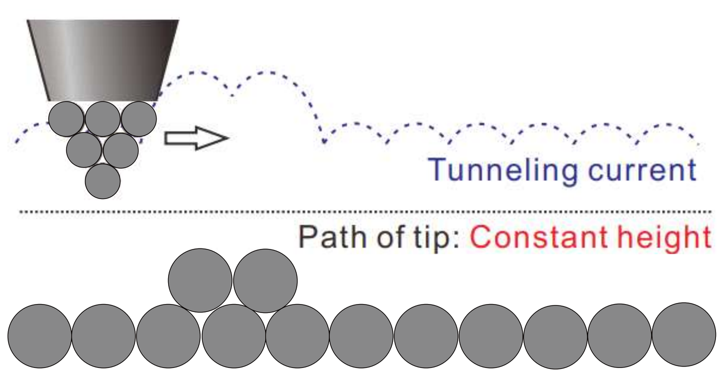
FeO(111) Films on Ag(100) System



- **Figure (a)** presents closed FeO(111) monolayer with domain boundaries on Ag(100).
- **Figure (b)** presents large, flat islands growing on the Ag(100) terraces and partially embedded in the topmost silver layer at the step edges.

Experimental Details

Scanning Schematic Diagram



Note :

1. Before depositing Fe films, the Ag(001) was cleaned by cycles of Ar^+ sputtering and annealing.
2. Using an electron beam evaporator to deposit Fe films.
3. FeO films were grown by postdeposition oxidation of Fe monolayer with a base pressure of 1×10^{-7} mbar.
4. STM measurements were performed at 77 K in a UHV chamber with constant current mode.

Results and Discussion

Growth of FeO(111) Films on Ag(001)

- **Figure 1** presents the grain boundaries seen to separate domains of differing orientation. These features persist as the coverage is increased, and a closed FeO(111) monolayer film is formed (see **Figure 1 (a)**).
- When the coverage of Fe decreases to 0.36 ML, the image shows large and flat islands growing on the Ag(001) terraces and some islands partially embedded on the topmost silver layer at the step edge, as shown in **Figure 1 (b)**.
- When the coverage is 0.22 ML Fe deposited on to Ag(001), FeO(111) islands are observed both atop the Ag(001) surface and embedded in the top layer (see **Figure 1 (c)**), which means that the increase of the FeO island and the diffusion of surrounding Ag atoms can be explained as due to the surface oxidation. In other words, the migration of embedded Fe atoms to the surface is driven by surface oxidation.

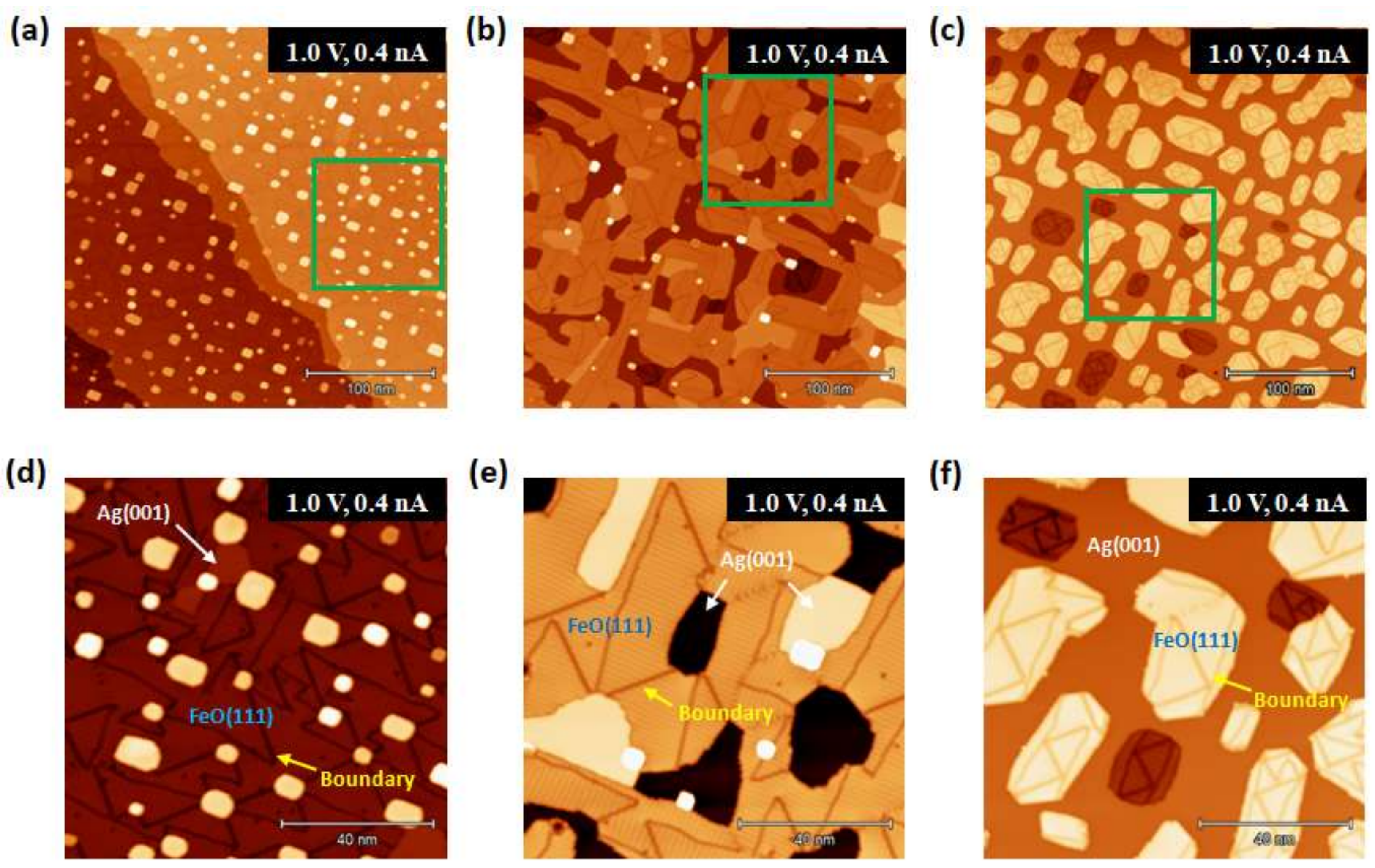


Fig. 1 STM topographic overview of Fe deposited onto Ag(001) surface at 250 K(scan parameters: U = +1.0 V, I = 0.4 nA). (a) Deposition of 0.72 ML Fe onto Ag(001) surface. (b) Deposition of 0.36 ML FeO onto Ag(001) surface. (c) Deposition of 0.22 ML FeO onto Ag(001) surface. (d) Zoom-in topography from the green square frame in (a). (e) Zoom-in topography from the green square frame in (b). (f) Zoom-in topography from the green square frame in (c).

Table1 Deposition coverage of Fe values.

Fe Deposition Time (min)	Fe Deposition Coverage (ML)	Oxidation Pressure (mbar)	Annealing Condition
5	0.72	1×10^{-7}	2 W 5 min
2.5	0.36		
1.5	0.22		

Atomically Resolved STM Images of FeO(111) Films on Ag(001)

- **Figure 2 (b)** shows a hexagonal atomic lattice (red diamond).
- The FeO(111) monolayer film exhibits a c(2 × 10), p(2 × 11), and c(2 × 12) unit cell due to lattice matching between the hexagonal overlayer and square substrate lattices, with a moire type modulation of the structure forming along these rows due to varying interfacial atomic arrangement (see **Figure 3**).

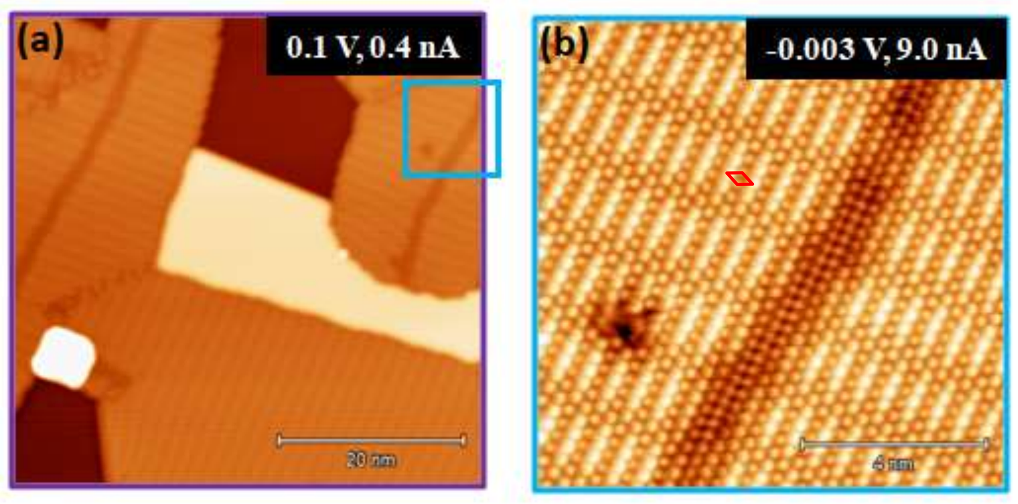


Fig. 2 Monolayer FeO(111) on Ag(001). (a) Large-scale STM image. (b) Atomically resolved STM image of Zoom-in topography from the blue square frame in (b).

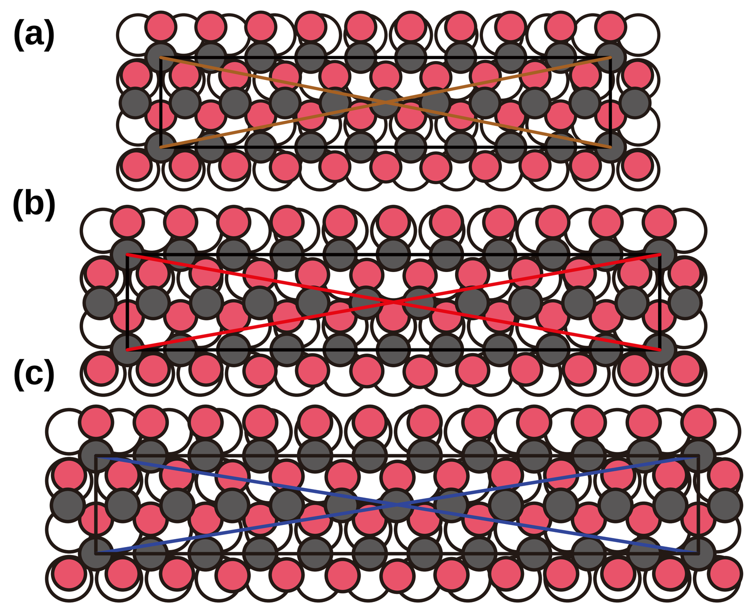


Fig. 4 Ball models of the FeO film structure. Red: oxygen. Dark gray: iron. White: silver. (a) c(2 × 10) unit cell. (b) p(2 × 11) unit cell. (c) c(2 × 12) unit cell.

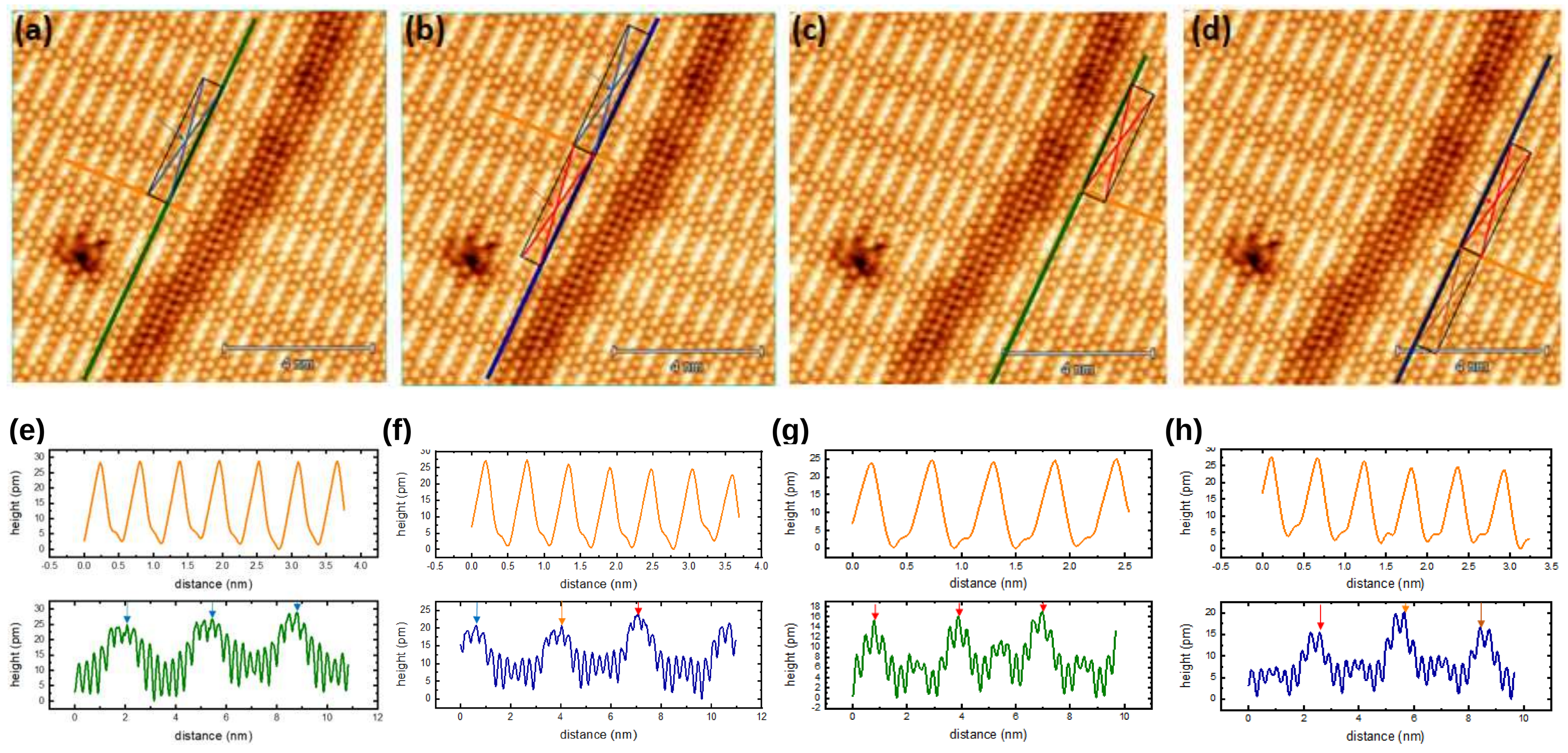


Fig. 3 Moire-type coincidence structure in STM images. (a) c(2 × 12) unit cell. (b) Coexistence of c(2 × 12) and p(2 × 11) unit cell. (c) p(2 × 11) unit cell. (d) Coexistence of c(2 × 10) and p(2 × 11) unit cell. (e) Line profiles indicated in (a) through identical atomic position. (f) Line profiles indicated in (b) through identical atomic position. (g) Line profiles indicated in (c) through identical atomic position. (h) Line profiles indicated in (d) through identical atomic position.

Line Defects in FeO(111) Films

- **Figure 6 (a)** presents the atomic structure of these dark domain boundaries separating three different domains of FeO(111).
- **Figure 8** presents schematic ball model of a FeO(100)-like boundary separating two mirrored domains of FeO(111), which reveals that one excess row of oxygen is present parallel to the boundary. Besides, when Fe atoms swap for O atoms in this model, which results in a structure incorporating instead one excess row of Fe.

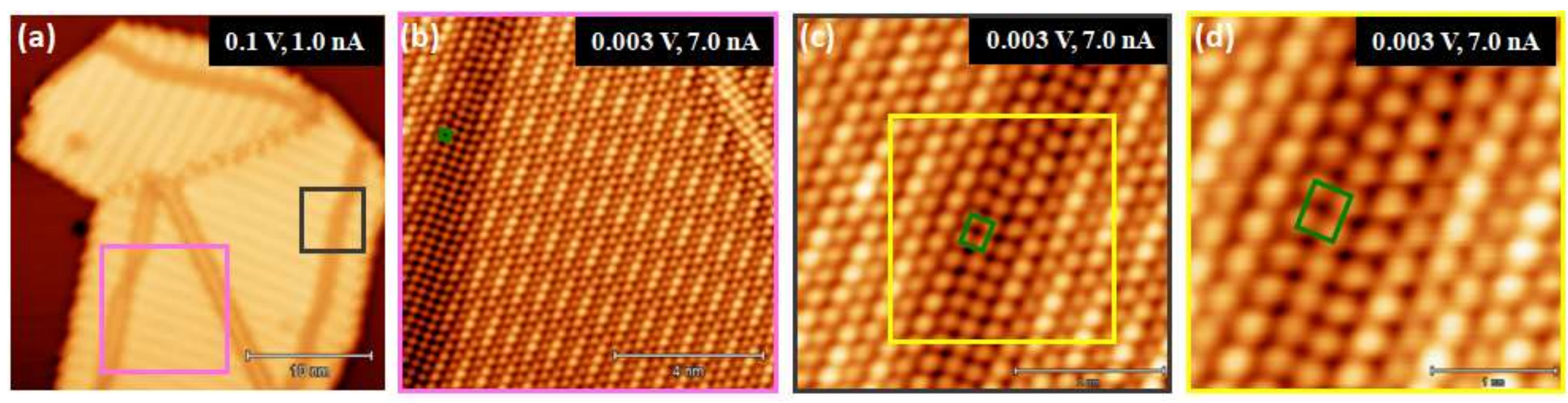


Fig. 6 STM images of FeO(111) domain boundaries. (a) FeO(111) monolayer with domain boundaries appearing as dark lines. (b) Zoom-in topography from the pink square frame in (a). (c) Zoom-in topography from the black square frame in (a). (d) Zoom-in topography from the ywllow square frame in (c).

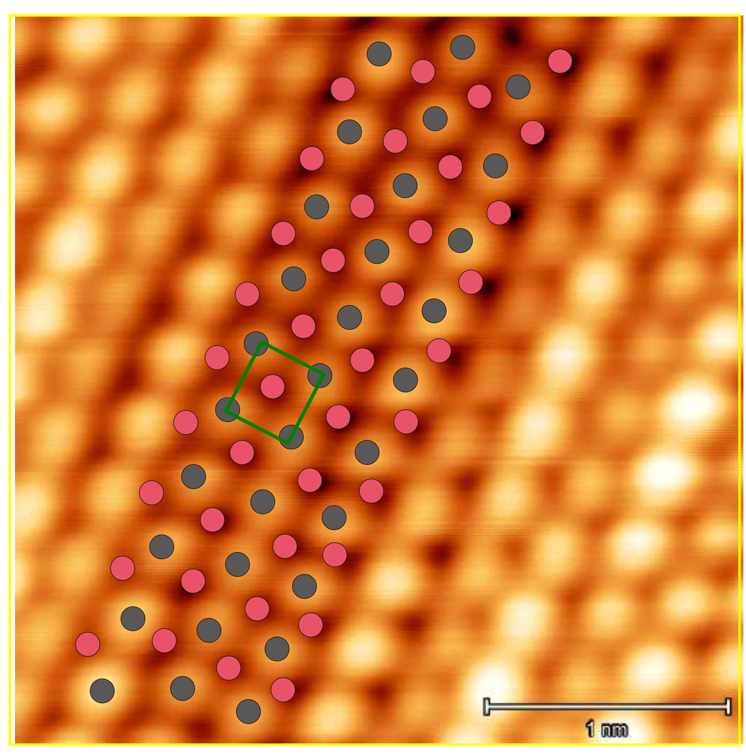


Fig. 7 Enlargements of STM images of domain boundaries of the atomic-scale contrast.

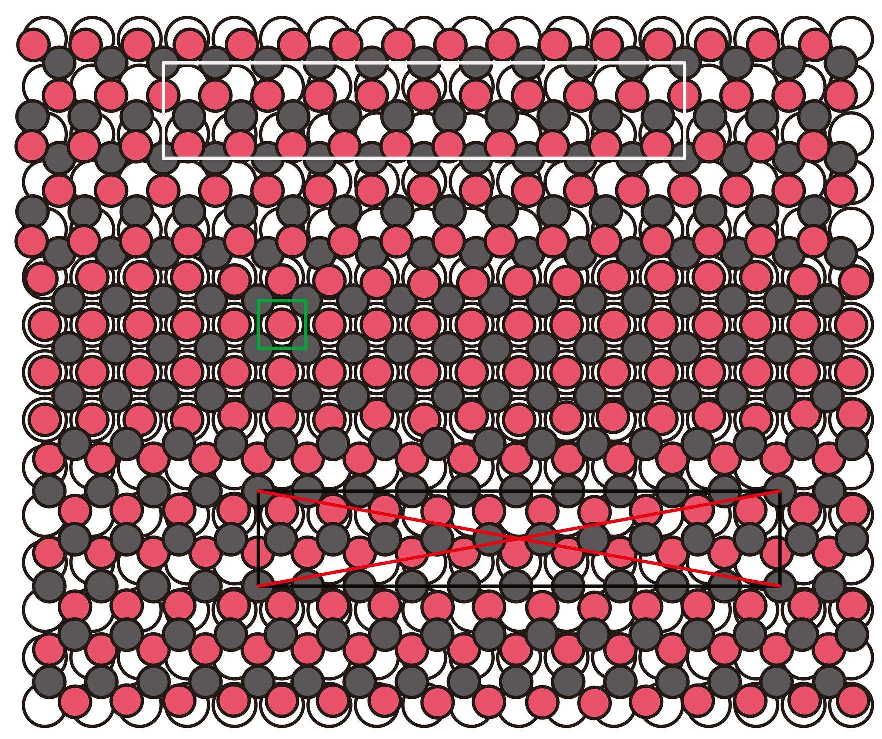


Fig. 8 Schematic ball model of a FeO(100)-like boundary separating two mirrored domains of FeO(111). Red: oxygen. Dark gray: iron.

Conclusion

In summary, a well-order FeO(111) thin film can be deposited on an Ag(001) surface by postdeoposition oxidation of Fe monolayer. The FeO(111) monolayer film exhibits different orientation that a c(2 × 10)/p(2 × 11)/c(2 × 12) unit cell can be observed by using high resolution scanning tunneling microscopy. Besides, line defects with locally square atomic coordination are formed due to the excess oxygen in FeO thin films. Furthermore, the oxide−metal interactions properties of ultrathin metal oxide films make them great potential materials in novel spintronic devices.

Reference

[1] “Growth and electronic and magnetic structure of iron oxide films on Pt(111)”, Phys. Rev. B, vol. 85, no. 7, pp. 075436

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