ELSEVIER

Surface Science 312 (1994) L748–L752

surface science

Surface Science Letters

Surface mobility on the Au(110) surface observed with scanning tunneling microscopy

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(Received 11 October 1993; accepted for publication 11 March 1994)

Abstract

The Au(110) surface is known to reconstruct in the missing row (1×2) structure. Large terraces along the $[1\bar{1}0]$ direction can be prepared. Here we report two-dimensional mass transport phenomena, i.e. structural changes and growth.

The Au(110) surface has been one of the first examples for surface reconstruction [1], that is the deviation of the surface atom positions from the bulk terminated structure. In case of Au(110)(1×2) a "missing row" structure can be observed in which every second $[1\bar{1}0]$ surface atom row is missing thereby forming (111) microfacets [2]. The surface forms terraces with a preference for steps along the $[1\bar{1}0]$ direction [2,3]. The Au(110) surface has been studied by all possible methods of surface structure analysis, the discussion of which and of the results obtained is not the aim of this paper. In the context of our STM (scanning tunneling microscopy) results presented here, we quote the previous STM work on the Au(110) surface only [4–8]. In Refs. [5,6] atomic resolution along the closed packed $[1\bar{1}0]$ direction was reported (nearest neighbour distance 2.88 Å) and – of course – along the [001] direction with a distance of 8.16 Å. Furthermore, the STM studies reveal other details not easily accessible by other methods, i.e. structural details of steps, dislocations, antiphase domain walls, the formation of (331) facets and also on the mass transport on the surface. The authors [5–8] also report a "mesoscopic" type structure, called "fish scale pattern" associated with a large number of antiphase boundaries. The step edges of this pattern are of the (111) type with kinks in the [001] direction. Time dependent observations have also been made, which revealed changes of step structure and, in one case, island decay. Time dependent island growth has also been reported for Au(111) [9].

We reproduced in our work the large (1×2) reconstructed terraces with extended $[1\bar{1}0]$ steps (details to be published [10]). We report the observation of spontaneous structural changes, which may give some insight into the discussion of the dynamics of crystal growth, time scales for reconstruction and "stability" of surfaces.

The experimental setup is a UHV-Omicron STM. Targets are prepared by sputtering and

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SSDI 0039-6028(94)00166-7

annealing. The preparation is controlled by LEED (low energy electron diffraction) and the STM imaging. Preparation, LEED and STM is done in different chambers of the vacuum system. Target transfer is done within the vacuum system. The Au crystal used has previously given good results in low energy ion scattering experiments with equal preparation [11]. We used W tips prepared by chemical etching [12]. The base pressure of the system is in the 10^{-11} Torr range. The missing row structure of Au(110)(1 × 2) can be found over a period of 4 days without further preparation. After sputter cleaning, a rather short (minutes) heating of the target to above 650 K, the order–disorder transition temperature of Au(110), is sufficient to produce a clean (1 × 2) LEED pattern. For the tunneling experiments we used a tip current of 0.5 nA and a bias voltage of 0.8 V. Fig. 1 shows an overview of a reconstructed Au(110)(1 × 2) surface with obvious resolution along the [001] direction where the atomic rows are separated by 8.15 Å. There is also resolution of the 2.88 Å atomic distance along [1$\bar{1}$0]

Table 1
Time dependent size of the structures observed in Figs. 2a–2d

Time(s)	Whisker 1		Whisker 2		Island	
	L (Å)	W (Å)	L (Å)	W (Å)	L (Å)	W (Å)
0	290	40	0	0	0	0
300	260	40	50	32	200	16
420	250	40	40	32	330	16
540	280	32	60	16	350	16

not shown here [10]. In Figs. 2a–2d time dependent changes of whisker-like structures and a case of island growth is reported. The (white) peninsula structure with its main orientation along [1$\bar{1}$0] narrows down to 100 Å and then to a 40 Å wide whisker. A width of 40 Å parallel to [001] comprise 5 atomic [1$\bar{1}$0] rows of the reconstructed structure (2a). Five minutes later the 40 Å whisker has grown a 30 Å expansion. Furthermore in the upper right hand corner a 200 Å long island appeared with a width of 2 rows or 16 Å. In the case of the dissolving island reported previously [6] the "final" width was also 2 rows. The contin-

Fig. 1. Grey-scale image of an STM topograph from the (1 × 2) reconstructed Au(110) surface. Area = 500 Å × 500 Å, V_t = 0.8 V, I_t = 0.5 nA.

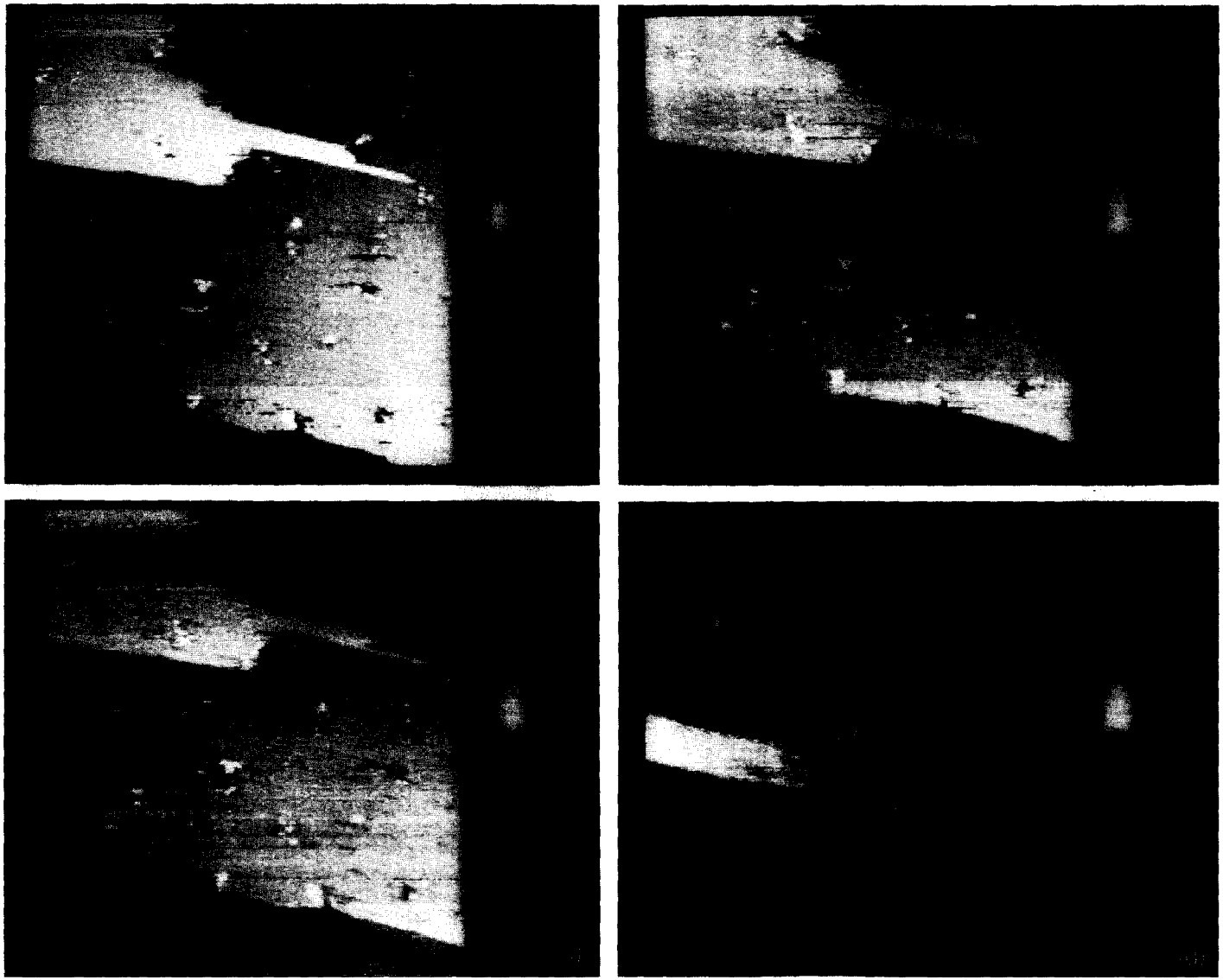

Fig. 2. Time study of a 2000 Å×2000 Å area (except in 2d where the area is only 1000 Å×1000 Å) with a pointed peninsula in the upper half. The tip of the peninsula gets longer and narrower during observation. Note the formation of the longish island in the upper right quarter. The time intervals between the measurements and the size of the structures are listed in Table 1. The outermost needle-shaped structure is denoted whisker 2; whisker 1 extends from whisker 2 up to the broadening. These STM topographs have been recorded at $V_t = +0.74$ V and $I_t = 0.54$ nA.

uing changes of the whiskers and the island could be followed for a total time of 20 min. The changes are listed in Table 1.

From the areas of the structure the number of atoms moved can be estimated, e.g. the final size of the island corresponds to 250 atoms. The distances over which the atoms are moving are of the order of 100 Å, quite obvious for the whisker case, where it is safely assumed that the length growth is partly fed by a decrease in width. This process is therefore similar to the growth process of 3D whiskers.

The diffusion coefficients for Au on Au are known [13] and can be used to estimate whether the transport phenomena found are feasible.

The surface diffusion coefficient can be estimated from $D_s \approx 0.014$ [cm^2/s] $\exp(-\epsilon T_m/RT)$ where $\epsilon = 13$ cal/mol · K, T_m is the melting temperature (T_m(Au) = 1334 K, $R = 1.986$ cal/mol · K). This gives D_s (300 K) $\approx 3 \times 10^{-15}$ cm^2/s. An average travel distance for 100 s is estimated from $\bar{X} = 2\sqrt{Dt} = 100$ Å. So the experimentally observed length changes are within the limits of known diffusion parameters. In case of the structural changes of the whisker it is safe to assume that the main part of the atomic motion occurs inside the [1$\bar{1}$0] channels. The total length of the whisker increases from 290 to 340 Å, with about a 10% loss of total area. These losses may involve cross channel motion. The island formation involves certainly cross channel motion. It may be fed from the neighbourhood or from the whisker. However on Fig. 2d there is some evidence for trough formation (dark features parallel to [1$\bar{1}$0]). These troughs would then be the source of atoms. This could be evidence for a pre-roughening as expected by theory [14] albeit this theory is still disputed. Also in the case that the island growth is fed from the terrace the distances the atoms have to travel are smaller than about 100 Å, i.e. smaller than the diffusion length estimated, since the troughs are closer than 100 Å to the island. From the point of view of thermodynamics it is to be expected that if islands dissolve [6] island growth ought to be observable.

The results cast some light on the old discussion whether there is enough time for the mass transport necessary to convert the (1 × 1) surface into a (1 × 2) surface [15,16]. On Au(110) there may be no problem the way it is usually prepared, i.e. sputter cleaning at room temperature, annealing for minutes at about 700 K followed by the rather slow (0.5 h) cooling down to room temperature. Previously it was argued [16] that travelling times of atoms are too short assuming that steps are the only source to form the (1 × 2) "overlayer". If the island formation plus a feeding from flat terraces are a possible alternative the time scale is sufficient. On Pt(110) where a metastable (1 × 1) surface can be prepared, and where the phase transition can be performed within 100 s [16] the situation may be different. The Pt(110)(1 × 1) seems to be well ordered. For Au(110)(1 × 1) this is certainly not the case. LEED patterns are rather diffuse. STM patterns with atomic resolution have not been reported so far. We have looked at a clean, freshly sputtered, unannealed Au(110) surface with the STM and found "cloudy" images even in cases in which atomic resolution even along [1$\bar{1}$0] was achieved after annealing [10].

We thank I.S.T. Tsong (Arizona State University) and P. Varga (T.U. Wien) for many helpful discussions.

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