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## The Pt(110) surface studied by STM and RHEED

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### Abstract

The Pt(110) surface reconstructs after the proper preparation in  $(1 \times 2)$  phase. The structure is called “missing row” structure, because in the surface every other [110] surface chain is not occupied. The STM analysis identifies this structure and shows also a characteristic step structure. The RHEED is used to study the phase transition of the surface which occurs at  $960 \pm 30$  K. The transition is of the 2D Ising type, i.e., an order–disorder transition.

*Keywords:* Metallic surfaces; Platinum; Reflection high-energy electron diffraction (RHEED); Scanning tunneling microscopy; Single crystal surfaces; Surface structure, morphology, roughness, and topography; Surface thermodynamics

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The Pt(110) surface has been studied in great detail by many experimental techniques. Like the Au(110) surface the Pt surface shows a  $(1 \times 2)$  reconstruction after the proper preparation at room temperature. Whereas Au is relatively easy to prepare, and it was probably for that reason that the first surface to be found showing reconstruction, Pt, tends to form higher order  $(1 \times n)$  structures with  $n > 2$  too. The structural data of both surfaces are rather well known. In the case of Pt(110) structural data are based on LEED [1,2], MEIS [3], X-ray diffraction [4] and RHEED [5]. Most of the theoretical papers can be found in a recent review [6]. The theoretical interest is quite fundamental, i.e., the existence of a 2D Ising transition is per se a very fascinating subject. Since in this contribution here we will concentrate on the experimental value of the phase transition temperature we mention explicitly the

theoretical prediction of 750 K [7]. There are five quite different experimental temperatures  $T_c$  published for the order–disorder transition ranging from  $855 \pm 15$  K [5],  $940 \pm 50$  K [8],  $960 \pm 5$  K [9], 1080 K [10] to  $1100 \pm 30$  K [11], thus covering a range of 250 K. The experiments used RHEED, photoemission, LEED, X-ray diffraction and LEED, respectively. The surfaces were in all cases prepared conventionally by sputtering and heating cycles. The surface cleanliness was checked by Auger electron spectroscopy (AES). The value of the critical temperature is influenced by impurities, e.g., Si and/or oxygen cause at concentrations in the percent range of a monolayer a shift of  $T_c$  up to 1140 K for, e.g., 1.5% oxygen [12]. The adsorption of CO causes a  $(1 \times 2) \rightarrow (1 \times 1)$  transformation [11]. The details of this  $(1 \times 1)$  phase have been studied by STM [13]. Here we use a clean  $(1 \times 2)$  surface which is controlled by STM – to speak the pathology of surface science – and which is then studied by RHEED quasi in situ.

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The STM-defined surface shows the phase transition at  $960 \pm 30$  K, a result which narrows the possible range of  $T_c$  considerably.

The experimental setup has been used previously for an analysis of Au(110) [14]. The experiment is based on an OMICRON-STM system. The

vacuum chamber containing the STM is joined by an “analysis” chamber. The analysis chamber is equipped with a STAIB RHEED electron gun, a LEED screen on which the electron diffraction spot intensity is measured with a video camera, and an electrostatic Perkin-Elmer  $180^\circ$  analyser

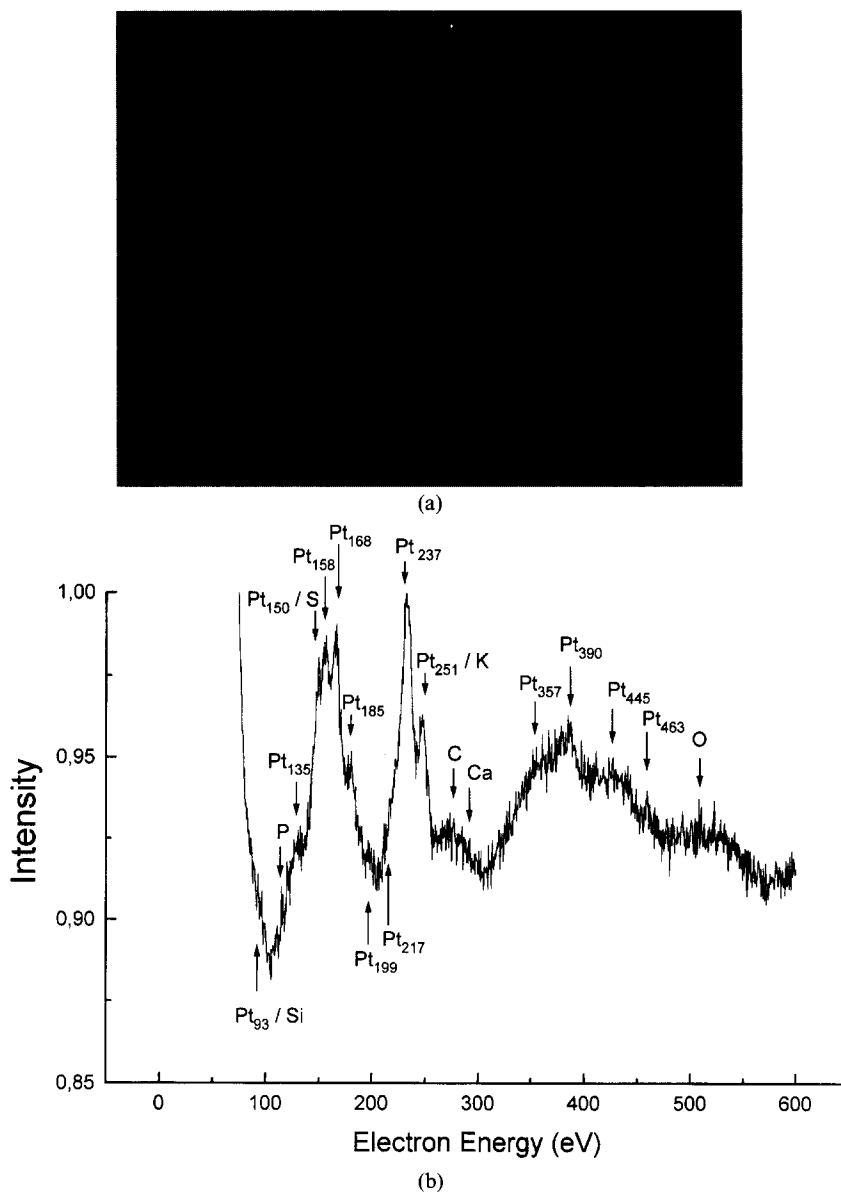


Fig. 1. (a) RHEED pattern at 915 K of Pt(110) ( $1 \times 2$ ). (b) Auger-electron spectrum (AES) of clean Pt(110) ( $1 \times 2$ ) at room temperature measured with a  $180^\circ$  electrostatic energy analyser. The arrows mark the position of possible impurities. The peak count rate is 80 counts/s.

used for AES. The Pt(110) surface is prepared in an adjacent “preparation chamber” by the usual cycles of sputtering and annealing.

Fig. 1 shows a RHEED pattern at 915 K, below the phase transformation, together with an AE-spectrum at room temperature. Besides the Pt peaks there are no identifiable peaks. Apart from

the trivial C and O peaks, the impurities to be found are the rather obnoxious Si traces which have also been reported previously [5,12]. These impurities, when present, need oxygen treatment as well as sputtering. With improved cleanliness we find an improved quality of STM results. Fig. 2 shows a  $250 \times 250 \text{ \AA}^2$  overview of the clean Pt(110)

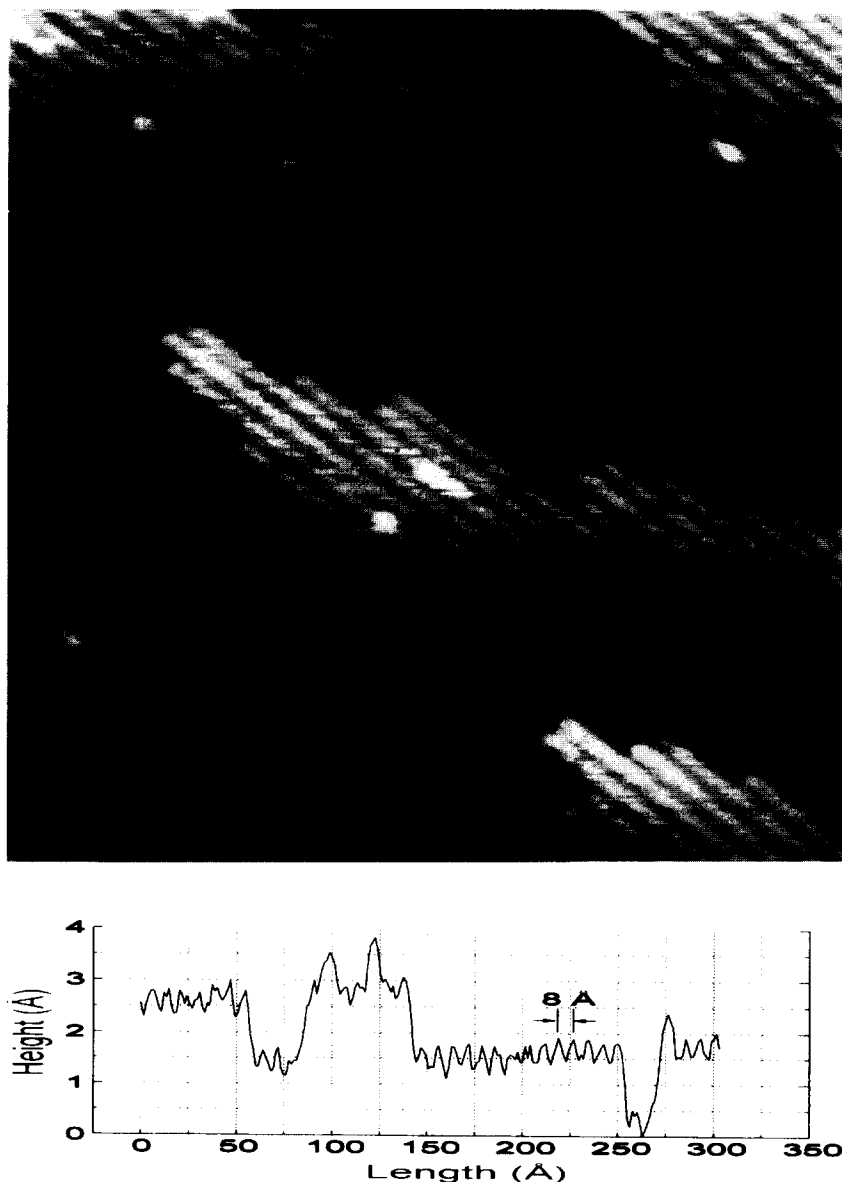


Fig. 2. STM view of the Pt(110)  $(1 \times 2)$  surface over  $250 \times 250 \text{ \AA}^2$ . The line scan shows the expected distance of  $7.84 \text{ \AA}$  for the distance between the  $[110]$  surface rows, which run under about  $40^\circ$  with respect to the lower edge of the figure. The steps are the height of one interplanar distance between (110) planes.

surface. The [110] surface rows are clearly resolved and show the expected lateral distance of  $7.84 \text{ \AA}^2$  (see height scan). The step structure is reminiscent of the “fish scale” pattern of the Au(110) surface [14–16]. In order to avoid [331] steps of higher energy compared to [111] steps, the surface forms this step pattern. Due to the  $(1 \times 2)$  reconstruction a terrace cannot be bordered by [111] steps only. Also phase boundaries can be minimized by this process [14–16]. The image quality of Fig. 2 is at least comparable to the best STM images published so far [13].

This well-characterized surface is then heated up while being observed by RHEED. The phase transition can be measured by registration of the spot intensities of the RHEED pattern. The heating is done by electron bombardment. The temperature is measured with a thermocouple at the crystal and by a pyrometer through a viewport of the analysis chamber. Fig. 3 shows the temperature dependence of the intensity of one of the half order diffraction spots. The line is a fit of the formula  $I/I_0 = A(T_c - T)^\gamma$  to the experimental data assuming  $\gamma = 0.125$ , i.e., a 2D Ising transition. The experimental data are not accurate enough to decide the question of whether it is Ising or not, but the  $T_c = 960 \pm 30 \text{ K}$  is certainly below  $1080 \text{ K}$  [10] and confirms the values of  $940 \pm 50 \text{ K}$  [8] and  $960 \pm 5 \text{ K}$  [9], respectively.

A discussion of the different experimental trans-

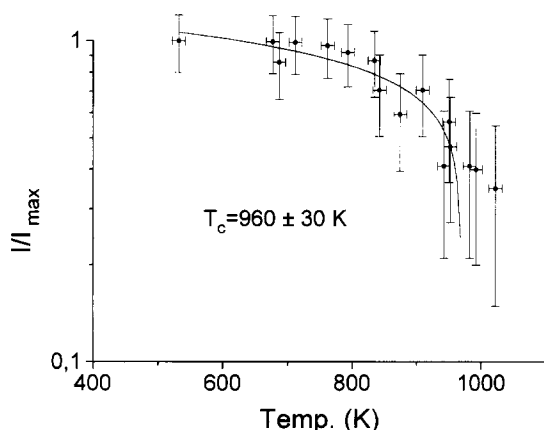


Fig. 3. The intensity of one of the half order spots of the RHEED pattern versus  $T$ . The line is a fit of  $I/I_0 = A(T_c - T)^{1/4}$ . The result is  $T_c = 960 \pm 30 \text{ K}$ .

formation temperatures is impeded by the fact that the impurities which cause observed shifts act already at the limit of detection of AES [12]. But it is beyond doubt that the combination of Si and O causes an increase of the value of the transformation temperature. The presence of Ca, probably brought to the surface by segregation, produces  $(1 \times 3)$  and  $(1 \pm 5)$  patterns [17]. We have never found traces of Ca or  $(1 \times 3)$  reconstructed areas in the STM [18]. A segregation of K up to a coverage of 0.02 in the temperature range  $850 < T < 1050 \text{ K}$  has also been reported [8]. The influence of K on the transformation temperature was studied and a correction applied, such that the value of  $940 \pm 50 \text{ K}$  is not affected by the contamination [8]. It is interesting to note that the authors [8] simply state that the phase transformation was not observed previously [11]. So far, no impurity has been reported which causes the transformation to decrease. This case is known for Au(110) where Sn shifts the  $(1 \times 2) \rightarrow (1 \times 1)$  to lower temperatures [19]. So, at present, we can only speculate about the causes for the different phase transition temperatures.

In support of our result, we may mention that we found the Au(110) transition temperature at the “canonical” value of  $650 \pm 30 \text{ K}$  in the same STM/RHEED system [14]. That is, the temperature calibration is probably accurate.

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