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Surface channeling experiments on Pb(110)

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Low energy ion scattering techniques at 2 keV with Ne^+ are used to study the surface structure of Pb(110) around 400 K. Surface channeling reveals a phase transition at this temperature. Surface blocking shows that the surface phase transition is of the roughening type.

1. Introduction

The Pb(110) surface shows different phenomena of interest for surface and solid state physics. The effect of surface melting was first found by medium energy ion scattering (MEIS) on Pb(110) by Frenken and Van der Veen [1]. About 30 K below the bulk melting temperature of 600.7 K the top surface layers are in a state of disorder which is best characterised as "quasi-liquid". This is proven by the logarithmic increase of the thickness of the liquid layer with temperature [2–4] and by X-ray experiments showing the liquid layer having about the proper density [5]. Low energy ion scattering experiments have confirmed the surface melting effect [6] and gave evidence for further effects in the so called "premelting regime" [7]. In this region, extending from about room temperature to the surface melting temperature, a host of effects has been reported studied by a variety of techniques [4–8]. Of major interest for the report here is the possible "roughening transition" at about 400 K. The roughening is understood as a change from a "flat" surface to one whose height-height correlation diverges [9]. This transition is initiated by an increasing step density [10]. We found a significant change of the surface channeling behaviour in the temperature range around 400 K [5]. In the present paper we report more detailed results using two types of ion scattering experiments, i.e. surface channeling and surface blocking [11].

2. Experiments and results

The surface channeling method makes use of a 2 keV Ne ion beam incident at a grazing angle onto the surface. All scattered particles are measured using a position sensitive detector consisting of a set of three microchannel-plates and a resistive anode. The number of ions incident on the detector are counted via an appropriate interface [12]. Fig. 1 shows results of the Pb(110) surface for two azimuthal directions and two temperatures. At low temperatures and for an azimuthal direction along a low index surface direction we find the expected "half-moon" pattern. Here we show the case where the incident beam is parallel to the $\langle 1\bar{1}0 \rangle$ surface half channels. The glancing angle of incidence of 5° is below the critical angle of channeling for the Pb surface [11]. When the temperature is raised above 400 K the pattern changes to an almost isotropic distribution of scattered particles. Similar isotropic patterns are found from the liquid surface [5] and for a random direction (Fig. 1). Random means that the incident beam direction is oriented parallel to a high index surface direction, i. e. 27.5° off the $\langle 1\bar{1}0 \rangle$ directions. This is a confirmation of the previously reported "major" change in the surface channeling [6] probably related to the surface roughening. (Note: we used a new crystal here. The previous crystal was molten to calibrate the temperature scale).

The surface blocking experiment exploits the shadow cone effect [13]. The incident beam probes the surface at an angle above the critical angle for channeling, here 11°, for high index directions (Fig. 2). Hence for the low index surface directions a detector at a large scattering angle measures no reflected particles, because all particles are scattered into forward directions from a perfect, step-free surface. When the azimuthal angle is varied double scattering becomes possible, because for high index directions neighbouring atoms are outside the shadow cones. The azimuthal distributions (Fig. 2) represent a real space pattern of the surface structure. The intensity in the minima is a measure for the smoothness of the surface. This finding is analoguous to the behaviour of the minimum yield in high energy bulk channeling experiments. When the temperature of the surface is raised we observe an increase of

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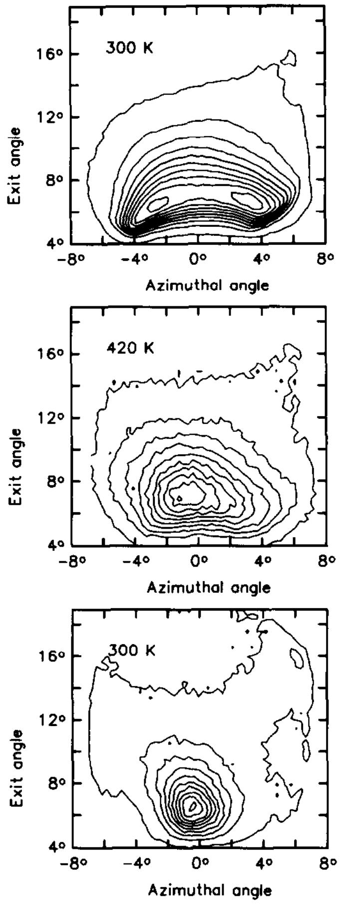

Fig. 1. Channeling patterns from the Pb (110) surface with 2 keV Ne ions incident at a grazing angle of 5°. The exit angle is measured from the surface, the outgoing azimuthal angle is measured relative to the ⟨1$\bar{1}$0⟩ surface directions (top and middle) and relative to a ⟨random⟩ direction 27.5° off the ⟨1$\bar{1}$0⟩ directions.

the minimum yields along the low index directions (Fig. 2). The yield increase can be caused by steps and adatoms. The comparison with Au(110) gives evidence for a roughening transition.

3. Discussion

The channeling pattern of the ⟨1$\bar{1}$0⟩ directions change from the half-moon pattern to the isotropic pattern within 10 K at 410 K reversibly, i. e. this is the signature of a phase transition [14,15]. We find that for the ⟨1$\bar{1}$2⟩ half channels the transition is "delayed" by 50 K. These findings will be published in detail elsewhere [15]. Here we concentrate the discussion on the blocking results, i. e. intensity vs azimuthal angle data. A qualitative understanding

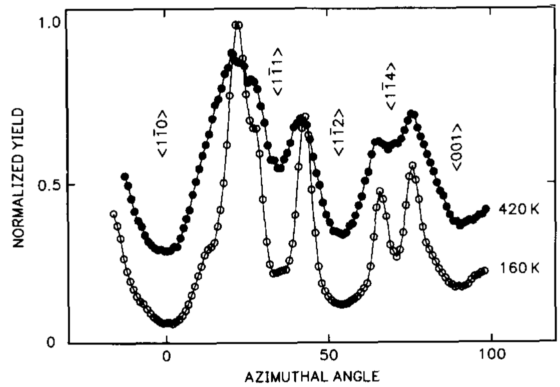

Fig. 2. Surface blocking patterns of Pb(110) at 160 K (o) and at 420 K (•). 2 keV Ne ions at a grazing angle of incidence of 11° are detected at a scattering angle of 165° by a time-of-flight method, i.e. the neutrals are detected. The incident azimuthal angle is covering all crystallographic directions of the surface.

of the results is obtained by comparison with corresponding Au(110) data (Fig. 3) [16]. The Au surface at room temperature is reconstructed in the "missing row" structure. This is seen as the difference of the Pb(110) pattern at 160 K compared to the Au(110) pattern at room temperature. Especially the deep ⟨1$\bar{1}$4⟩ and ⟨3$\bar{3}$4⟩ channels of Au are the signature of the (1 × 2) missing row reconstruction [16]. We note also the differences in the minimum yields of the two surfaces indicating a considerably lower step density of the Au surface. The Au(110) surface undergoes an order–disorder transition at 650 K [16–18]. This Ising transition is accompanied by a roughening transition as indicated by our previous results [16] and clearly demonstrated by atom diffraction exper-

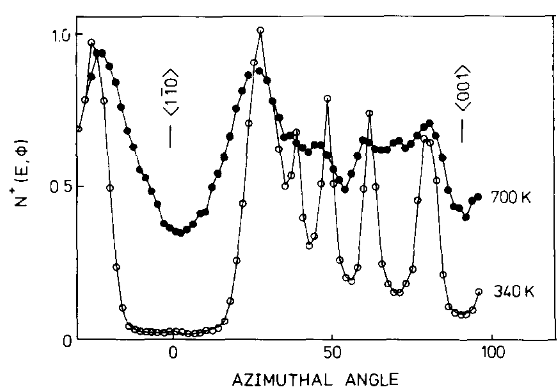

Fig. 3. Surface blocking pattern of Au(110) at room temperature (o) in the missing row structure and at 700 K (•) in the disordered, "rough" phase. Experimental conditions as in Fig. 2.

iments [19]. So we know that the Au(110) surface at 700 K (Fig. 3) is a disordered and rough surface in basically the (1 × 1) structure. The inspection of the Pb(110) pattern at 420 K in comparison to the Au(110) pattern at 700 K shows a clear resemblance. So we conclude that the structure of the two surfaces are equal, i.e. we have qualitative evidence that the Pb(110) surface at 420 K is indeed a rough surface.

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