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# Influence of the Substrate on RHEED Oscillations of Growing Pb Films

Reflection high-energy electron diffraction (RHEED) is a very useful technique for studying the growth and surface analysis of thin epitaxial structures prepared by molecular beam epitaxy (MBE). In particular the technique of the RHEED intensity oscillations has been used to analyze and to control thin film growth [1]. RHEED intensity oscillations are observed during the growth of the ultrathin metallic and semiconducting films [2–5]. In this report we present a part of our studies of the growth of Pb ultrathin films on Si(111) substrates.

## EXPERIMENTAL

The ultrathin Pb films were prepared in an UHV system pumped by an ion pump and Ti-sublimation pump with a liquid-nitrogen (LN)-cooled cold wall. The base pressure was better than $1 \times 10^{-10}$ hPa and the pressure during deposition was kept below $4 \times 10^{-10}$ hPa.

The substrates were Si(111) wafers with about 6 $\Omega$cm specific resistivity at room temperature and typical dimensions $18 \times 4 \times 0.6$ mm. Before deposition, Si surface was cleaned by flashing for few seconds at about 1550 K and resulted in the appearance of a sharp $(7 \times 7)$ superstructure RHEED patterns [6]. The substrate could be cooled to about 110 K.

The second type of the surface was prepared by deposition of about 1.2 monolayer (ML) of Au on the Si surface with $(7 \times 7)$ superstructure. Au deposits were annealed for 0.5 min at about 950 K and then the temperature was gradually lowered to about 500 K during 3 min. This type of surface indicated well-developed $(6 \times 6)$Au superstructure RHEED pattern [7–9].

The third type of the substrate was Si(111)-$(7 \times 7)$ with thin film of Pb (Si(111)-Pb). The buffers were prepared by deposition of 20 ML-thick layer of Pb on Si(111)-$(7 \times 7)$ substrates. During the deposition of the buffers the temperature of Si substrates was equal to about 110 K. However, the buffers were first annealed to the room temperature and next, before they were used to produce thin films, they were cooled again to the temperature of about 110 K.

## RESULTS AND DISCUSSION

We observed RHEED intensity oscillations for ultrathin films of Pb during the growth on all substrates at 110 K. Typical results of the RHEED specular beam intensity oscillations measured during the growth of Pb films on Si(111)-(7 × 7), Si(111)-(6 × 6)Au and Si(111)-Pb surfaces at 110 K are shown in Fig. 1. During the growth of the Pb thin films on the pure Si(111)-(7 × 7) surface (Fig. 1a) the oscillations became regular after the deposition of about 5 ML of Pb. When Pb grows on Si(111)-(6 × 6)Au surfaces (Fig. 1b), the regular oscillations with some superposed additional peaks are seen. In the third case the regular and single oscillations develop from the very beginning (Fig. 1c).

For Pb on Si(111)-(7 × 7) the regular oscillations appeared after structural transition which takes place after reaching the thickness of about 5 ML. This was apparent from RHEED pattern shape. The intensity of Si(111)-(7 × 7) spots was strongly dumped after reaching of 1-2 Mα thickness of Pb. The background intensity characteristic of the strongly disordered crystal structure was only seen. After deposition of about 5 ML of Pb this pattern showed the well developed smooth streaks. This structural transition of Pb occurs within about 1 ML narrow range of Pb thicknesses.

The laminar growth of Pb from the very beginning was seen upon growing of Pb on Si(111)-(6 × 6)Au and Si(111)-Pb (Fig. 1b and Fig. 1c). The existence of the additional peaks for Pb on Si(111)-(6 × 6)Au was caused by the interference effects on the Si(111)-(6 × 6)Au/Pb interface. For this type of the substrate the streaks were seen after deposition of about 1 ML of Pb.

The additional structure caused by interference effects were absent during deposition of Pb onto Si with Pb buffer layer (Fig. 1c). The last type of the substrate is very convenient for studying the growth mode by using the RHEED method. The exclusion of the substrate influence on the RHEED intensity oscillations is important for the detailed analysis of RHEED phenomena within the framework of RHEED dynamic theory. In the paper [9] it was shown that during the growth of Pb-In alloy films on this type of the substrates it was possible to study experimentally and theoretically the fine structures in RHEED oscillations. These structures in RHEED intensity oscillations manifest as the second set of the peaks and it was attributed to the perfect growth mode of the ultrathin film. This opens new possibilities for studying the growth phenomena of the metallic films [9].

RHEED intensity oscillations occur not only during the growth at 110 K but also at higher temperatures. Fig. 2 shows the RHEED intensity during the growth of the Pb layers on clean Si(111)-(7 × 7) surfaces at various temperatures. However, the amplitudes decrease with increasing temperature and no oscillations were seen above 180 K. The streaks become sharper and modulated along their length with

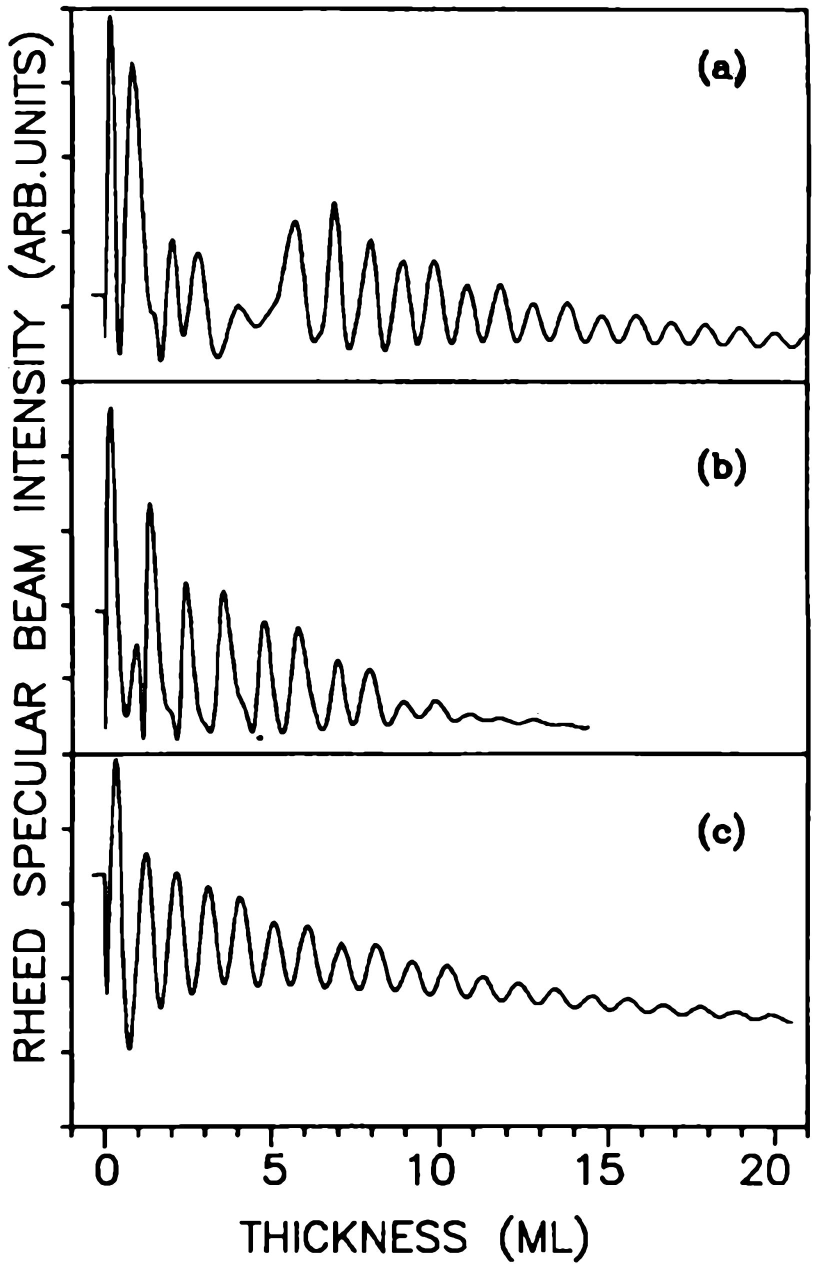


Fig. 1. RHEED specular beam intensity oscillations during the growth of Pb films at 110 K: a) on Si(111)-(7 x 7), b) Si(111)-(6 x 6)Au and c) on Si(111)-(7 x 7) with Pb buffer layer. Electron beam energy is 20 keV, azimuth Si[11$\bar{2}$], polar angle is 0.30°

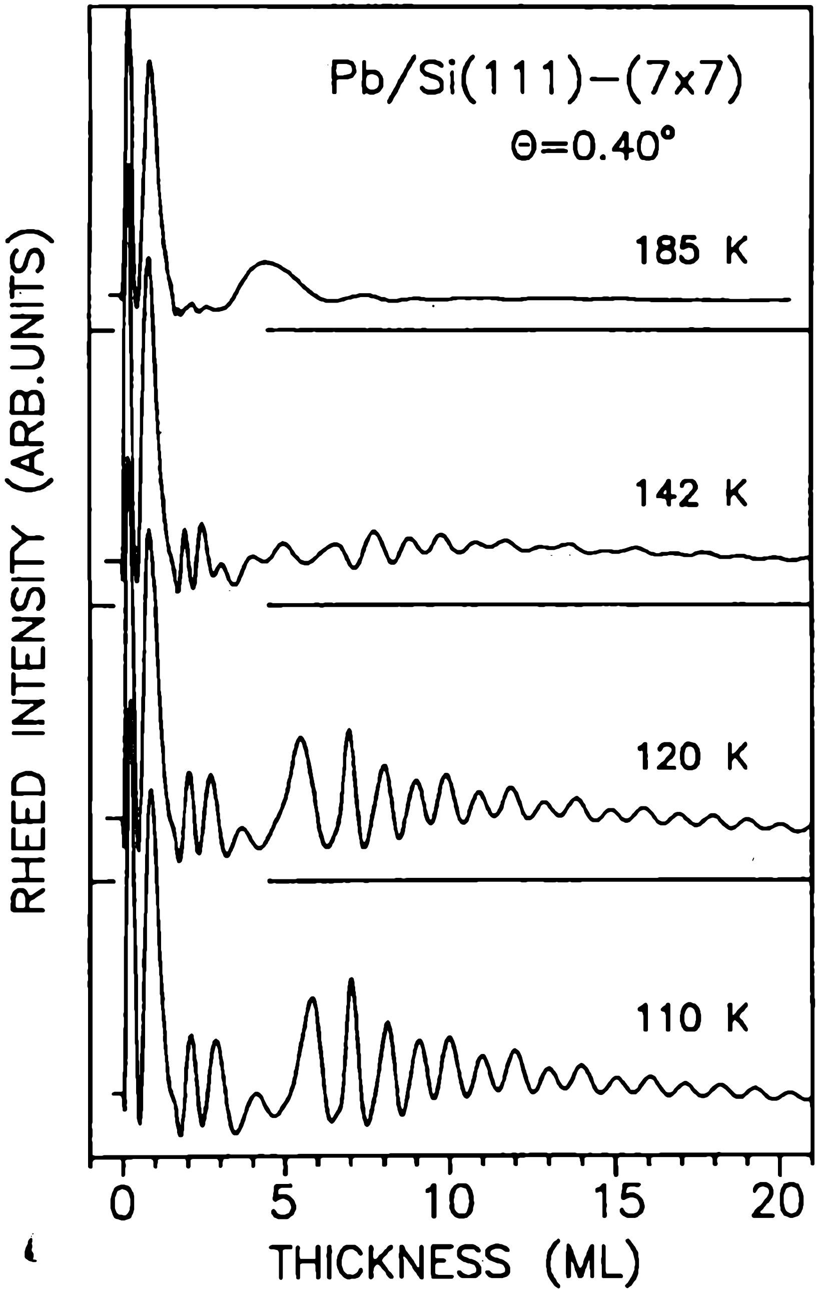


Fig. 2. RHEED specular beam intensity oscillations during the growth of Pb layers for different temperatures on clean Si(111)-(7 × 7) surfaces. Electron beam energy is 20 keV, polar angle is 0.40°

increasing temperature. This suggests three-dimensional crystal growth mode of Pb in a form of the larger grain size.

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