Growth and Characterization of Sb Overlayers on InP(110)

K. Li, C. R. Bonapace and A. Kahn
Department of Electrical Engineering and Computer Science
Princeton University
Princeton, NJ 08544

Abstract

The InP(110)-Sb(1) interface, formed on cleaved room temperature InP, is studied with LEED and AES. We show that Sb grows in monolayer-high islands which coalesce at \( \vartheta = 1 \text{ML} \) to form a well ordered (1x1) structure. The nature of this overlayer is discussed. We study the growth of the amorphous Sb layer for \( \vartheta > 1 \text{ML} \). Finally, we examine the resistance of the ordered single monolayer to oxidation and draw some comparisons with other III-V(110)-Sb interfaces.

1. Introduction

Sb over layers formed on room temperature GaAs(110) surfaces exhibit several interesting features. At monolayer (1ML) coverage, the overlayer is atomically ordered [1-3] and displays a stable saturated (1x1) structure. The atomic geometry of this overlayer involves two Sb atoms per unit cell and consists of chains running on the surface along the (110) direction (fig.1). The position of the adatoms preserves the original symmetry of the (110) unit cell. The geometry of this interface is dominated by the hybridization of the Sb \( p_z \) orbitals with the substrate dangling orbitals [2,4,5]. The \( p_x \) and \( p_y \) orbitals of neighboring Sb's form the Sb-Sb bonds in the chain. The adatoms nearly unrelax the substrate surface geometry and occupy positions close to those of the Ga and As atoms in the first missing GaAs layer. This ordered overlayer also exhibits interesting growth properties. It grows in random size islands which are detected through characteristic broadening of LEED diffraction spots [1]. These islands coalesce when the coverage reaches 1ML.

The study of other Sb-III-V(110) interfaces is desirable in order to determine whether the Sb-GaAs structure results from a specific match between the adatom and the substrate, or whether Sb can play a similar role on other III-V surfaces, i.e. InP(110) or GaP(110). Observations of ordered Sb over layers on InP(110) suggest the latter [6]. In addition, recent energy minimization calculations of Sb on InP, GaP, InAs and InSb have predicted geometries very similar to that of Sb on GaAs(110) [4]. Of general interest, of course, are the chemical and structural characteristics of all column V elements on III-V surfaces, as these elements are directly involved in the growth of compound semiconductors and heterojunctions by evaporation techniques.

In this paper, we examine the deposition of Sb on cleaved InP(110) and establish that the growth characteristics, namely the formation of ordered domains at submonolayer coverage and the coalescence of these domains into a well ordered (1x1) structure, are similar to those of Sb on GaAs(110). Additional diffraction features, i.e. splitting of LEED spots due to a regular distribution of these submonolayer domains, are also reported. We observe a 3-stage growth corresponding to the formation of a homogeneous first monolayer followed by the growth of a thicker amorphous film. Finally, we report oxygen exposure experiments which demonstrate the passivity of the first monolayer and the strength of its bonds to the substrate.

![Atomic geometry of 1ML Sb adsorbed at room temperature on GaAs(110)](image-url)
2. Experimental Techniques

The experiments were performed in a UHV chamber equipped with a single pass cylindrical mirror analyzer and a 4 grid LEED optics, at a base pressure of $6 \times 10^{-11}$ torr. Sb was evaporated on freshly cleaved InP(110) surfaces from a resistively heated molybdenum basket. The evaporation rate, typically 1.5 Å/min., was controlled with a quartz-crystal thickness monitor. The effective thickness of one Sb monolayer on InP(110) is $2.48\text{Å}$ ($1\text{ML} = 8.210^{14}$ atoms/cm$^2$). A sticking coefficient of unity for Sb on InP was also assumed. The temperature of the sample, which could be cooled to 100°K, was monitored with a chromel-alumel thermocouple. AES was used to evaluate the atomic composition of the interface and the homogeneity of the overlayer as a function of coverage. LEED I-V profiles were recorded from the phosphor screen with a spot photometer. O$_2$ dosing of InP(110)-Sb(1ML) and InP(110)-Sb(40ML) were performed for total exposures ranging between $10^6$L and $10^9$L. During these experiments, all precautions were taken to prevent excitation of molecular oxygen.

3. Results and Discussion

From bulk thermodynamics, one expects the InP-Sb interface to be unreactive, i.e. no P-Sb exchange reaction takes place ($\Delta H_r(\text{InP}) = -21.2\text{kcal/mole} > \Delta H_r(\text{InSb}) = -7\text{kcal/mole}$[7]). This assumption is consistent with photoemission spectroscopy measurements [6] and with the results presented below. The adsorption of Sb on InP(110), monitored by AES, proceeds in three stages (fig.2): (1) layer-by-layer growth for $\vartheta < 1\text{ML}$, (2) surface diffusion and clustering for $1\text{ML} < \vartheta < 10\text{ML}$, (3) formation of an homogeneous amorphous film for $\vartheta > 10\text{ML}$. We now examine these stages separately.

At submonolayer coverage, the normalized substrate peaks decrease exponentially as a function of coverage (fig.2). This dependence yields effective escape depths $\lambda_P = 3.7\text{Å}$ and $\lambda_{In} = 7.6\text{Å}$ for P(121ev) and In(401ev) Auger electrons, respectively, numbers which are consistent with the layer-by-layer formation of an homogeneous overlayer [8]. When the coverage reaches 1ML, a break occurs in the slope of the curves due to a change in the growth mode of the overlayer. The $\lambda$'s given above therefore suggest that for $\vartheta < 1\text{ML}$, the adatoms follow a layer-by-layer growth and form a complete saturated overlayer at 1ML. The anomalous rise of the In peak amplitude at 0.25ML (fig.2) has been carefully considered. Repeated checks having eliminated the possibility of an erroneous data point, we believe it is due to a change in shape of the AES In peak (which induces a change in the amplitude of its first derivative) upon initial bonding with Sb. Above 0.25ML, further increase of the In peak amplitude corresponding to more surface In bound to Sb is offset by the damping of the substrate signal by the overlayer.

The assumption of a layer-by-layer submonolayer growth is confirmed by LEED. The freshly cleaved InP sample produces a sharp (1x1) pattern which suggests a highly perfect surface with little defect and step density (fig.3 a). The LEED I-V profiles are in excel-

![Fig. 2](image-url) Normalized AES peak amplitudes for Sb (455ev), In (401ev) and P (121ev) as a function of Sb deposition on room temperature cleaved InP(110). Arrows indicate critical coverages for which changes occur in the growth of the overlayer.