THE ION INDUCED ANGULAR DISTRIBUTION PATTERNS OF GaAs(110) AND Al/GaAs(110)

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I. Introduction

The angular distribution of secondary ions has been known to reflect the structure of the surface since the first observations of angular anisotropies of ejected Cu atoms by Wehner in the mid–1950's[1]. Similar observations of these anisotropies from covalently bonded crystals (Si,[2] Ge,[3] and GaAs[4)]) followed as their technological importance was realized. Unfortunately, the methods of data collection required an ion dose large enough to provide a measurably thick film of sputtered material. Consequently, any surface structure information was lost due to ion beam damage effects.

We report, for the first time, the Ga^+ ion angular distribution from the GaAs(110) surface under low–dose normal incidence Ar^+ ion bombardment. We also report the pattern of Al desorbed from .5 to 1.0 monolayer (ML) coverage of Al/GaAs(110). The pattern of Ga^+ ions desorbed from a clean GaAs(110) surface is shown in Fig. 1, and the Ga^+ and Al^+ azimuthal distributions simultaneously collected at a polar angle of 45° from the surface normal are shown in Fig. 2. The surface structure and definition of the azimuths are shown in Fig. 3. From a simple geometrical analysis of the pattern of ions shown in Fig. 1, it is determined that the dominant mechanism of ion ejection from clean GaAs(110) is a specific collisional sequence which promotes desorption of surface atoms along the direction defined by their bonds to second–layer atoms. As can be seen in fig. 2, the pattern of Al^+ ion emission does not resemble that of Ga^+ ions and is significantly less intense. These observations are in agreement with a model of the overlayer in which the Al adatoms weakly interact with the surface forming 2–dimensional "raft–like" structures as has been proposed previously.[5]

II. Experimental Procedure

GaAs(110) wafers were obtained from M/A Com Laser Diodes, Inc. and were degreased in trichloroethane, acetone, ethanol, and methanol before etching in a 5:1:1 solution of sulfuric acid:water:peroxide. Surfaces were prepared by cycles of ion

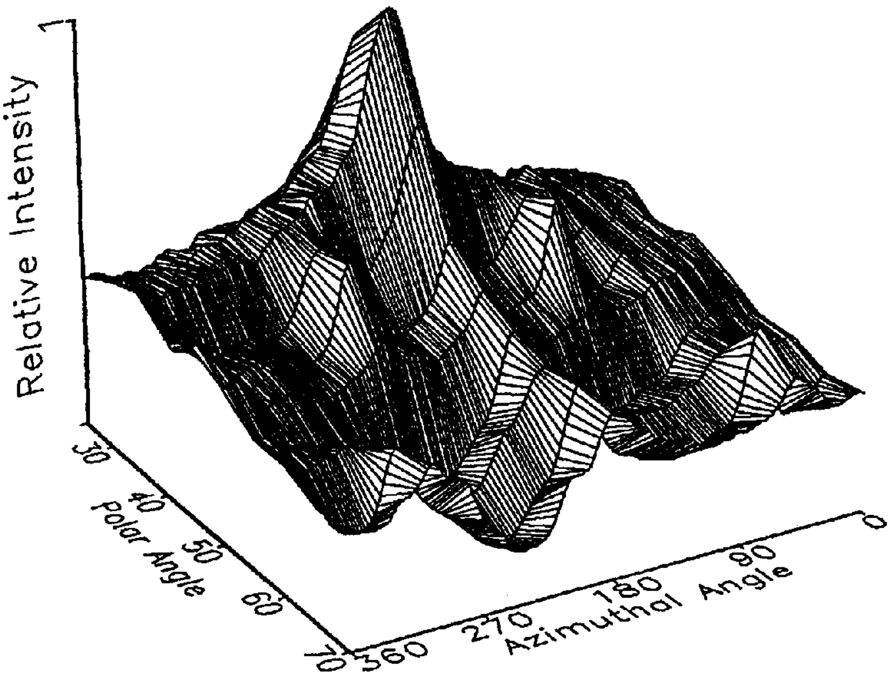

Fig. 1. Azimuthal and polar angular distributions of Ga^+ ions desorbed from GaAs(110) after bombardment with 3 keV Ar^+ ions at normal incidence.

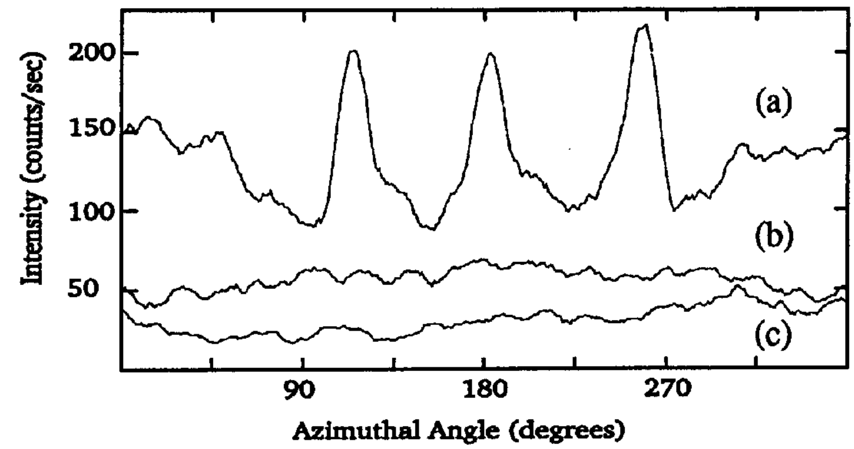

Fig. 2. The azimuthal angle distributions of (a) Ga^+ ions before annealing (b) Al^+ ions before annealing, and (c) Al^+ ions after annealing are plotted for a detection angle of 45° from the surface normal.

bombardment and annealing to 585°C. This procedure provided clean ordered surfaces as determined by low energy electron diffraction (LEED), Auger electron spectroscopy (AES) and SIMS. The total ion dose was maintained at static levels by measuring the ion current and limiting the total exposure time to less than one tenth of the time required to desorb a monolayer of material. Typically a 2 nA beam was focused into a 1 mm spot

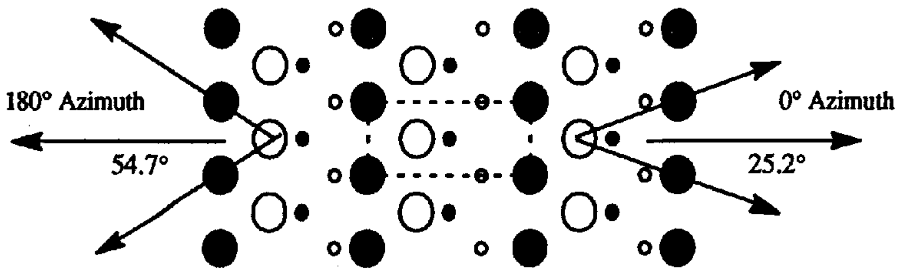

Fig. 3 The surface structure of GaAs(110). The large circles represent surface layer atoms while the smaller circles represent atoms in the second layer. The open circles represent Ga atoms while the hatched circles are As atoms. The arrows indicate the directions at which blocking should occur at glancing exit angles. The dotted square indicates the unit cell.

impingent on a 3 mm radius circle of the crystal for a period of 15 min as the crystal was rotated azimuthally over 3 full revolutions. The Al coverages were determined from measurements of the Al flux made on an ion gauge placed at the metal deposition position. The flux was determined from the ratio of the ion gauge signal with the Al oven open to the signal of Ga at a known GaAs growth rate and corrected for their relative sensitivities.

III. Results and Discussion

The analysis of the Ga^+ ion angular distribution hinges on the correct identification of 0° and 180° azimuths. This is best accomplished from the analysis of the azimuthal distribution of Ga^+ ions at glancing exit angles. From Fig. 3, it can be seen that along the 0° azimuth two blocking features, ie. dips in the signal, should exist at 25.2° relative to this direction, while along the 180° azimuth two blocking features should exist at 54.7° relative to this direction. These features are seen near 25.2° and 334.8°, and at 234.7° and 125.3°, respectively in Fig. 1 at a polar angle of 65°. The differences between the predicted and measured intensity dips arise from contributions from both surface reconstruction and the simplicity of the analysis which ignores the interaction of ejecting ions with more than one surface atom.[6]

With the patterns at glancing exit angles clearly identifying the crystallographic azimuths, it is possible to address the nature of dominant feature of the distribution. From fig. 3, it can be seen that the surface Ga atoms bind on top of a triangle of As atoms, one of which is in the second layer. This pyramid structure is tipped 35° in the 0° azimuth. From this geometry, it would seem that the surface Ga atom should eject directly from the top of the pyramid and consequently in the 0° azimuth. However, the largest peak occurs at a polar angle of 35° along the 180° azimuth. The position of this peak indicates that the mechanism of ejection is not due to randomized momentum, but arises from a series of specific collisions. These conclusions have been confirmed by recent simulations of the ion bombardment of Si(110).[7] These results also agree with measurements of the distribution of Ga atoms ejected under ion bombardment.[8]

The last important feature of the angular distribution of Ga^+ ions is the pair of peaks located 76° on each side of the 180° azimuth at a polar angle of 45°. This three–peak structure, seen in fig. 2, is highly sensitive to ion dose. As a result of the sensitivity of this particular azimuthal scan to surface damage it was used as a monitor of the degree of surface order present after each surface preparation and at the end of each experiment.

The azimuthal pattern of Al^+ and Ga^+ ions collected simultaneously at a polar angle of 45° are shown in fig. 2 along with the azimuthal pattern of Al^+ after a 5 min anneal at 585°C. The Al coverage was determined to be 0.75 ML. Two points are important to note from this figure. First, the angular pattern of Al^+ ions does not bear any resemblance to the established Ga^+ ion pattern before or after annealing. This fact has led us to believe that if any cation exchange reaction is taking place it must be under Al clusters and thus is not detectable by SIMS. Secondly, there is only a small signal observed for the Al^+ ions at coverages up to 1 ML, presumably due to a low ionization probability. A comparison of the Pauling electronegativities[9] of Ga(2.01), Al(1.51), and As(2.18) would indicate that the Al^+ signal should dominate, followed by the signals of Ga^+ and As^+. However, the observed Ga^+ signal is the most intense, followed by Al^+ and lastly As^+. This indicates that the Al overlayer must only be weakly interacting with the GaAs and therefore must be "metallic" in nature. All of the above observations are in good agreement with the "raft" model of the overlayer proposed by Zunger.[5]

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