Ion Irradiation Induce Surface Modifications of InSb(001)

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الملخص :
تم بحث نمو التشاكيل (morphology) على سطح InSb(001) تحت الاشعاع الايونى بواسطة مايكروسكوب القوة الذرية(AFM) في ظرف فراغ فوق العالي(UHV).
تم تعريض السطح InSb(001) لحزمة ايونية لاركون ذات طاقة (٤كيلو فولت) و بفيض (٤ X ١٠^١٧ اي ون سم^-٢) عند زوايا مختلفة بين (٠-٨٠) درجة . تم ملاحظة عدة انواع من التراكيب الدقيقة كفجوات ، حلقات والنقط النانوية وكذلك التموج السطحي اعتمادا على زاوية سقوط الايون. حيث تبين عند زاوية السقوط (٤٥ درجة) ان اتجاه التموج عمودية على مسقط سقوط الايونات بينما عند زاوية (٨٠ درجة) التموج يتجه على طول مسقط الايون. و فسرت النتائج بناءً على نظرية برادلى و هاربر لتعديل السطوح.

ABSTRACT
Morphological development on InSb(001) surfaces, under ion irradiation, has been investigated by means of Atomic Force Microscopy in UHV conditions. The InSb(001) surface has been exposed to Ar^+ beam with varying incident angles (from 0° to 80° off-normal) for energy 4.0 keV and fluence $4x10^{17}$ ion/cm^2. Different kinds of nanostructures, depending on ion incident angle, have been observed on the irradiated surfaces such as nanocavities, or nanorings and nanodots, preferentially for close to normal incidence, and well-order ripples for the oblique incidence. The formation of ripple structures on InSb(001) surfaces as a function of the incidence angle has been observed. The orientation of the ripples has been found to be incident angle dependent and it is perpendicular, or parallel to the ion beam projection on the irradiated surface for angles of 45° and 80°, respectively.. The results have been discussed in terms of ballistic processes of sputtering and Bradley Harper theory for surface modifications.

Keywords:

Surface modification, Surface patterning, Ion irradiation, Ripples, III-V semiconducting compound, B-H theory and Atomic force microscopy.

INTRODUCTION

Surface Pattern formation in nanometer-scale on crystalline and amorphous solids using ion bombardment has become a topic of rapidly increasing interest. However, with the fast-growing interest in nanotechnology, ion beam sputtering is frequently regarded as an alternative process for the generation of various nanostructured surfaces or interfaces via self organization. One reason is certainly the potential of such nanoscale patterns for various important applications in contemporary electronics, materials science, molecular biology, medicine. Regarding self-organization effects and spontaneous pattern formation during ion sputtering, the phenomenon of ripple formation on the irradiated surfaces was intensely studied for a last few decades. Since the first detection of ripple structures on glass surfaces by Navez et al. [1], ripple formation has been also observed for a number of
different materials [2–12] and became become an active area of research due to its possible application in nanotechnology.

The main mechanism that determines the surface morphology of amorphous solids undergoing oblique ion bombardment was proposed by Bradley and Harper [13]. According to the linear continuum model of BH theory the patterning is dependent on the curvature dependent sputtering of the surface proposed by Sigmund [14], where, valley regions sputter faster than the convex (hill) regions, creating a instability on the surface. This instability is opposed by a smoothing mechanism, e.g. surface diffusion or viscous flow, both being of thermal [15] or ion bombardment origin [16]. The interplay between these two processes governed a characteristic wavelength for the pattern [13].

In the present work, we have studied the evolution of the ripple amplitude with increasing incident angle for a fixed energy and fluence of the ion beam at room temperature. The surface topographies have been investigated by means of Atomic force microscopy (AFM).

EXPERIMENTAL

All the experiments were performed in the ultra high vacuum(UHV) chambers having a vacuum of about 10^{-10}mb. The InSb(100) epi-ready wafers, from Kelpin Crystals (Neuhausen, Germany), with sizes of 5x5 mm^2 are clamped to a molybdenum plate with help of tungsten wires. The molybdenum plate is supported on the copper holder which can be heated by a resistor heater fixed inside the copper holder, the temperature is measured with Chromel-Alumel thermocouple fixed on the copper holder. The fresh sample is preannealed at 695 K for several hours. In order to get well define starting conditions, the InSb sample is further sputter-cleaned at 695 K by Ar^+ ion bombardment for 1 h (using a 0.7 keV energy ion beam, current about 1.5 μA, rastered over 2 cm^2, incidence angle of ± 60 off-normal), This procedure provides a clean and well-ordered surface showing a c(8 × 2) LEED pattern (Low energy electron diffraction) as shown in Figure (1)

For surface modification of such pre-prepared samples we use ion bombardment with a focused Ar^+ beam (the diameter of the beam spot below 1 mm) scanned over the entire sample area. The G 400 ion source have been used which is designed to clean the samples for surface analysis and the surface modification.

The clean surface was bombarded with 4.0 keV Ar^+ for the ion fluence of $4x10^{17}$ ions/cm^2 at various incident angle between 0^o and 90^o off-normal at room temperature. All measurements were conducted in vacuum by atomic force microscopy in contact mode (C-AFM) under vacuum condition (10^{-11} mb) using CP Park Scientific Instruments AFM microscope. The average wavelengths (ripple like structure) of the surface nanostructures are determined directly from AFM topography profiles as well as from 2D self-correlation functions of AFM images.

The Atomic Force Microscope is technique that can be used to analyze and characterize the samples surface at the microscope level, with very accurate resolution ranging from 100 μm to less than 1μm. The AFM operates as follow, an extremely fine sharp tip either come in contact or in very close proximity to the sample that is being imaged. This tip is usually a couple of microns long and often in the range 100Å in diameter (In this work we used silicon nitrite (SiN) tip with a nominal diameter about 10 nm). The tip is located at the free end of a cantilever that is 100 to 200μm long. The sample is then scanned beneath the tip. Different Forces either attract or repeal the tip. These deflections are recorded and processed using imaging software; the resulting image is a topographical representation of the sample that was just imaged. If you want to know about the sample rather than just a view of its surface, there are different imaging modes that are used for different types of analysis. Either different hardware or scanning techniques are required to obtain the data necessary for the analysis. The AFM can measure a number of characteristic properties of the sample that other forms of microscopy cannot reproduce.

In the present paper, we report on surface morphology modifications of an InSb(001) crystal induced by low-energy Ar^+ bombardment at various incident angle at room temperatures .

RESULTS AND DISCUSSION

None-contact AFM topography image of the treated surface show the nice terraces (the atomic layers) indicate well-ordered surface showing a c(8×2) LEED pattern as shown in Fig.(1). An experimental parameter which is rather easy to change in sputtering is the angle of incidence of the incoming ions relative to the normal to the average surface configuration, Fig. 2 shows the two dimensional view of the surface morphology obtained from the AFM images of InSb(001) samples bombarded with Ar^+ ion at various angles for a fluence of $4x10^{17}$ ions/cm^2 at room temperature. The corresponding surface profile of each AFM image is indicated at bottom of the image. The created structures is evident in both, the line profiles and 2D auto-correlation images on the right corner in the inset of the images, which are perpendicular to the direction of incident ion beam at about 45^o off-normal and parallel to the ion beam for the angle more than 60 degree. These results indicate that ripples appear only for a limited range of incidence angles, which, depending on materials and ions involved.

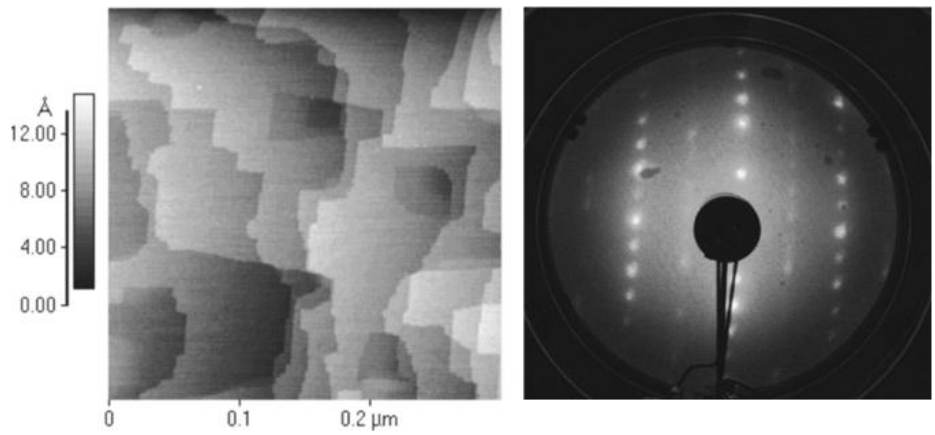

Fig. (1) Non-contact AFM image and the LEED pattern of the clean surface of InSb(001)

The created nanostructures in our experimental work are in the form of ripple patterns at about (θ=45^o) ion incidence, with a wave vector oriented parallel to the ion-beam direction. Also an alignment of ripple features at near-normal incidence (θ>60^o) and with the wave vector oriented perpendicular to the incoming ion beam appear have been observed. It is worth mentioning that all experimental studies reported here follow, as predicted by B-H theory, with the ballistic process of sputtering.

A close view of the morphologies clearly shows a pit and cavity (nanoring) like structure with different dimension depending on the angle of incidence. The period of the created nano-wire like structure in this stage of fluence, nanowire known as wavelength, is calculated by the line profile as shown at the bottom to the corresponding image and also from 2D self-correlation functions of AFM images nearly about 100nm.

The sputtering yield have been calculated using SRIM code simulation [17], for the projectile angle of incidence θ with respect to the surface normal, is shown in Fig.3. Generally, the yield reaches a maximum at angles between 60° and 80° before decreasing rapidly at larger angles. This decrease is related to an increased reflection of projectiles at near grazing incidence. At a more grazing incidence angle, less energy is deposited as the ion beam is reflected off the surface, and the yields decrease significantly. The influence of the angle is also governed by the surface structure of the target and the ion mass. For example, the incident angle of Ar^+ ion bombardment which gives the maximum sputtering yield is about 70^0 in this range of incidence angle well order ripple were created along the ion beam direction.

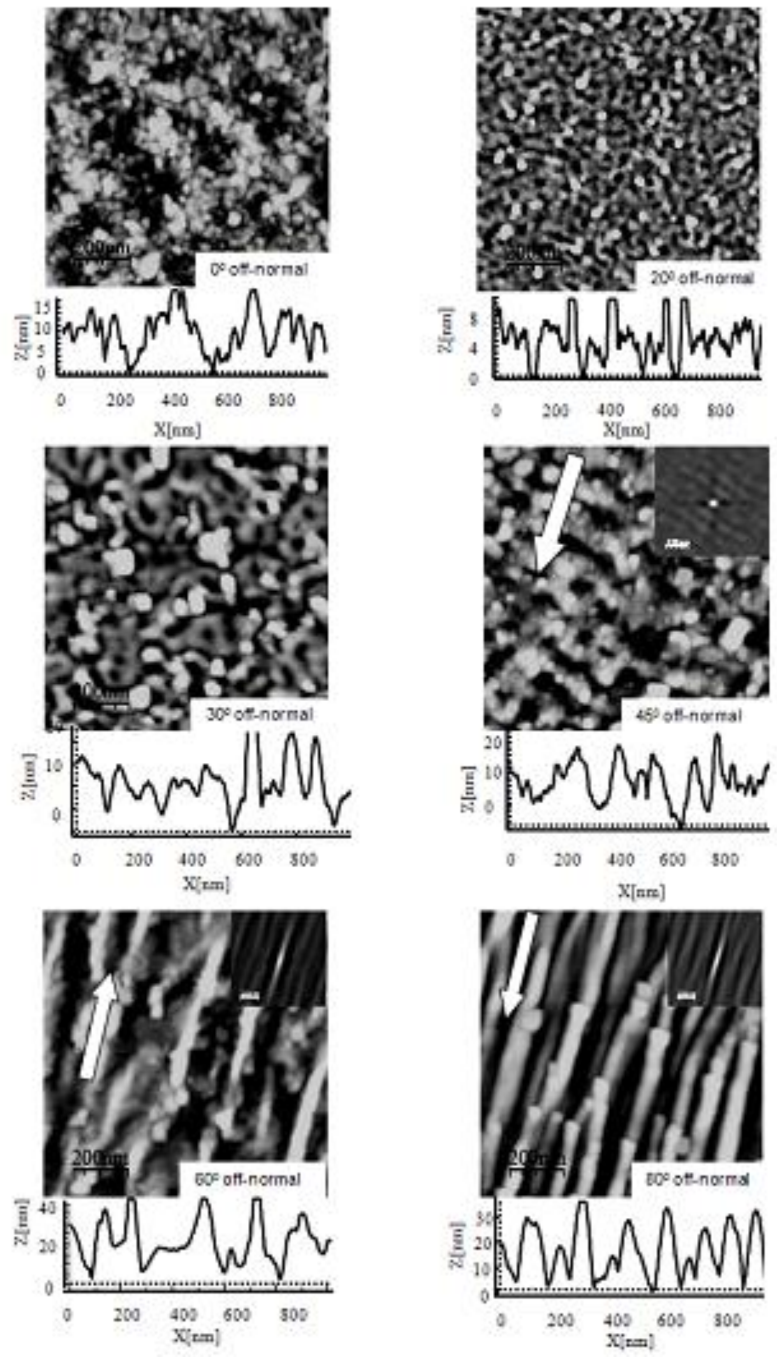

Fig. 2. Contact AFM images (1x1 μm^2) of the InSb(001) surfaces modified at various incident angle with 4.0 keV Ar^+ beam for the fluence $4x10^{17}$ ions/cm^2. The insets in the upper-right corners show 2-D self-correlation and

the arrows indicate the ion beam direction. The z-scale profiles taken along the line passes through the center of y-axis below each image. The images were taken in vacuum environment.

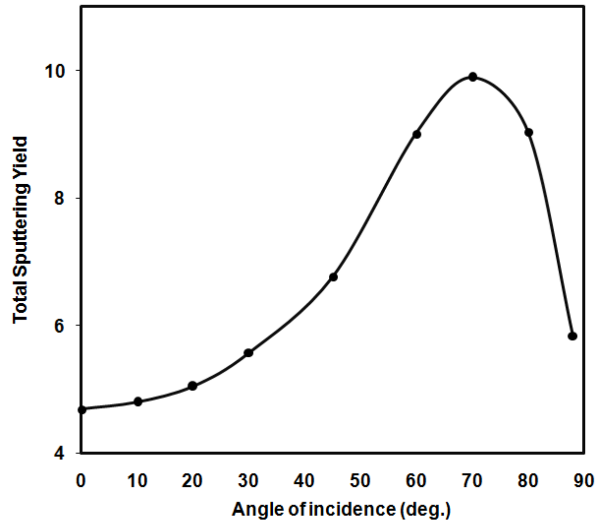

Fig. 3. Ion sputtering yields from InSb(001) surface, bombarding energy of 4.0 keV as a function of incident angle θ from the surface normal.

The evolution of the surface topography with ion incidence angle for erosion with Ar+ ions is quantitatively summarized in Fig. 4 where the dependence of the root-mean-square (rms) roughness on θ_{ions} is plotted

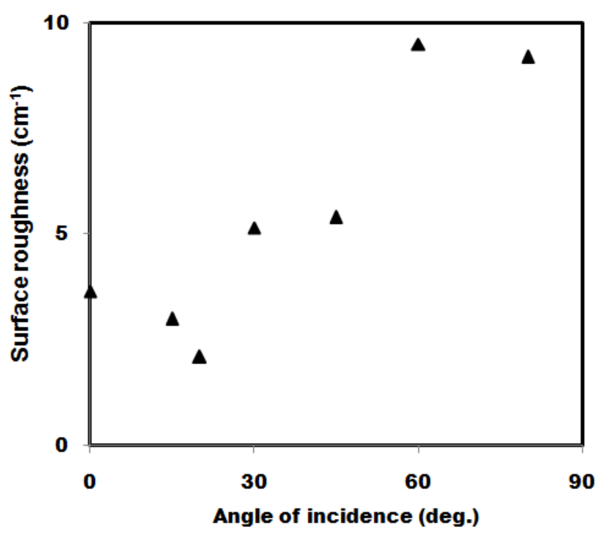

Fig. 4 Variation of RMS surface roughness of the InSb(001) surfaces as a function of incidence ion angle where the ion energy is 4 keV and fluence $4x10^{17}$ ion/cm^2 at RT.

The rms roughness can be taken as a measure for the height fluctuation on the surface-i.e., the nanostructure amplitude. Generally, at first bombarding ranging up to about 30° ion incidence, nanocavity and dots like patterns develop on the surface. By increasing the ion incidence angle the amplitude of the ripples nearly decrease (45^{o} incidence angle). Also for ion incidence angles between 60° and 80°, the surface remains rough but start to smoothing where well order ripples are created, especially at 80^{o} of incidence angle.

CONCLUSIONS

In conclusion, detailed studies of the ion-induced surface modification and nanostructuring at single crystal InSb (001) surface due to rare gas ion beam have been studied in an UHV environment by means of the contact mode atomic force microscopy. At the oblique incidence, for angles larger than 60° off-normal, a regular pattern of periodic ripples is formed for the ion fluences of 5×10^{17} ions/cm^2 at 4 keV ion energy. The RMS surface roughness is found to be angle dependent. The ripple wave vector is either perpendicular (for angles of incidence larger than 60°), or parallel (for angle about 45°) to the projection of the ion beam. The creation of ripple –like structure follow the perdition of Bradley- Harper theory.

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