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Surface modification of InGaAs/GaAs heterostructures by swift heavy ion irradiation

S. Dhamodaran [a], A.P. Pathak [a,*], D.K. Avasthi [b], T. Srinivasan [c]
R. Muralidharan [c], D. Emfietzoglou [d]

[a] *School of Physics, University of Hyderabad, Central University (P.O.), Hyderabad 500 046, India*
[b] *Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi 110 067, India*
[c] *Solid State Physics Laboratory, Timarpur, Delhi 110 054, India*
[d] *Medical Physics Department, Ioannina University, Ionnina, Greece*

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Abstract

We investigate the surface morphology of molecular beam epitaxy (MBE) grown InGaAs/GaAs(001) heterostructures using atomic force microscope (AFM) before and after irradiation. Samples with layer thicknesses below critical layer thickness (i.e. fully strained) have smooth surface where as, the samples grown beyond critical layer thickness have cross hatch patterns at the surface. The transition from smooth to cross-hatch pattern may be used to identify the onset of strain relaxation. The samples were subjected to swift heavy ion (SHI) irradiation using 150 MeV Ag^{12+} ions with a fixed fluence of 1×10^{13} ions/cm^2. The morphology of the strained samples was almost similar before and after irradiation where as, the partially relaxed samples were observed to have variations. The electronic energy loss of the incident ions which is dominant compared to the nuclear energy loss is effective to modify with the fluence used in the present study for partially relaxed samples. The relaxation of excited electron subsystem of the target results in the melting and re-growth which reflects in the surface morphology. The observed modifications at the surface may be attributed to (i) irradiation induced surface mass transport and (ii) interface modifications, where both these factors determine the surface morphology of heterostructures. The effects of irradiation on the surface and interface of the samples have been realized by AFM studies.

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Keywords: Heterostructures; Strain relaxation; AFM; Irradiation

1. Introduction

Ternary III–V semiconductors are of interest for both electronic and optical device applications. The growth of heterostructures on a lattice mismatched substrates with a uniform strain in the over-layer result in additional advantages. The strain lifts the degeneracy of the light-hole and heavy-hole states at the valence band maximum [1,2]. The confinement and strain effects on the band structures of lattice mismatched heterostructures are ideal to tailor the optical properties [3–5]. Such strained heterostructures are limited by a critical layer thickness, beyond which the uniform strain relaxes giving rise to misfit dislocations which leads to the degradation of device performance [6–8]. In heterostructures of zinc-blende structure (e.g. InGaAs/GaAs) with a small lattice mismatch grown on (001) oriented substrates the orthogonal arrays of 60° type dislocations along orthogonal $\langle 110 \rangle$ directions are formed. Such network of dislocations results in the formation of cross-hatch patterns at the surface. Atomic force microscopy (AFM) is capable of observing such well defined cross-hatch patterns [9]. The surface pattern of such struc-

* Corresponding author. Tel.: +91 40 23010181/23134316; fax: +91 40 23010181/23010227.
E-mail address: appsp@uohyd.ernet.in (A.P. Pathak).

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Table 1
AFM measurement and surface roughness

Samples on GaAs (layer thickness)	Sample ID		Surface roughness R_{rms} (nm)	Protrusions/holes size (height) in nm
$In_{0.1}Ga_{0.9}As$ (45 nm)	1005	U	0.954	700 (2–4)
		I	1.611	875 (3–5)
$In_{0.15}Ga_{0.85}As$ (45 nm)	1105	U	1.643	1000 (5–8)
		I	1.119	1000 (3–5)
$In_{0.2}Ga_{0.8}As$ (45 nm)	1205	U	0.953	–
		I	0.747	–
$In_{0.25}Ga_{0.75}As$ (45 nm)	1305	U	2.231	117 (6–9)
		I	2.514	180 (5–9)
$In_{0.18}Ga_{0.82}As$ (12 nm)	1203	U	3.960	–
		I	3.050	–
$In_{0.18}Ga_{0.82}As$ (36 nm)	0903	U	1.542	170 (2–4)
		I	1.297	110 (2–4)
$In_{0.18}Ga_{0.82}As$ (60 nm)	1003	U	2.618	175 (9–15)
		I	4.309	175 (11–22)
$In_{0.18}Ga_{0.82}As$ (96 nm)	1103	U	2.615	320 (5–9)
		I	2.361	387 (7–11)
$In_{0.1}Ga_{0.9}As$ (10 nm)	2701[a]	U	0.375	–
		I	0.932	–
$In_{0.1}Ga_{0.9}As$ (15 nm)	2601[a]	U	4.107	–
$In_{0.1}Ga_{0.9}As$ (25 nm)	4201[a]	U	3.000	–

[a] Samples with layer thickness below the critical layer thickness.

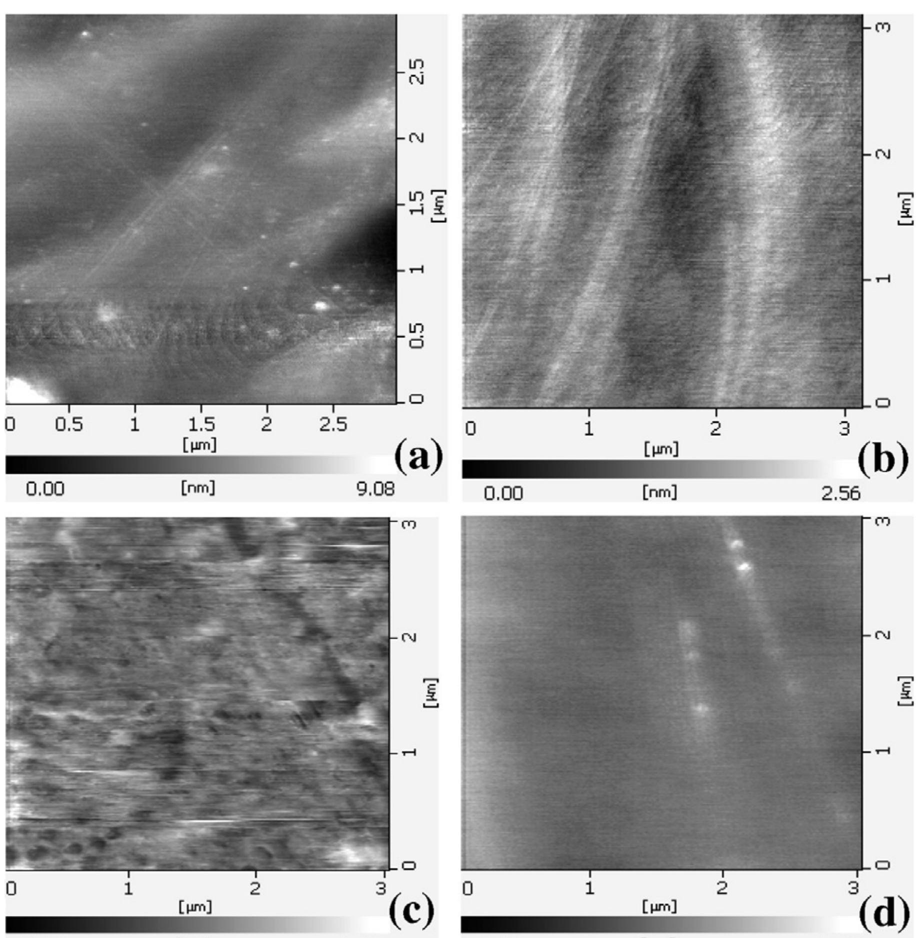

Fig. 1. Surface morphology of strained heterostructures of 10 (U and I), 15, 25 nm thick samples.