

MODIFICATION OF SILICON SURFACE UNDER MEDIUM ENERGY HEAVY ION BOMBARDMENT

THESIS SUBMITTED TO JADAVPUR UNIVERSITY FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY (SCIENCE)

By

Debi Prasad Datta

SAHA INSTITUTE OF NUCLEAR PHYSICS

1/AF BIDHAN NAGAR, KOLKATA 700064

April 2008

Contents

1	General Introduction	1
1.1	Motivation	2
1.2	Interactions of energetic ions with solid	4
1.3	Sputtering and implantation	13
1.4	Ion induced patterned morphology	15
1.5	Structural and compositional change in silicon under ion bombardment	16
1.6	Luminescence from ion induced silicon nanostructure	18
1.7	Outline of this thesis	19
2	Experimental Techniques	21
2.1	Introduction	22
2.2	Ion Implanter	22
2.2.1	Basics	22
2.2.2	The 200 kV High Current Ion Implanter	23
2.2.3	The sample holder	35
2.3	Atomic Force Microscopy (AFM)	37
2.3.1	Basics	37
2.3.2	AFM Measurements	39
2.4	Scanning Electron Microscopy (SEM)	41
2.4.1	Basics	41
2.4.2	Energy dispersive x-ray spectrometry (EDS) in a FEGSEM	45
2.5	Transmission Electron Microscopy (TEM)	51

2.6	Photoluminescence	54
3	Ripple morphology on amorphous surface induced by off-normally incident inert gas ion bombardment : Theoretical approaches	56
3.1	Introduction	57
3.2	Classifying a rough surface in several ways	57
3.3	Statistical method of analyzing a randomly rough surface	58
3.3.1	The average surface height	58
3.3.2	The RMS roughness and scaling properties of surfaces	59
3.3.3	Correlation functions	60
3.3.4	Lateral correlation length and system correlation length	60
3.3.5	The power spectrum	62
3.4	Extraction of roughness parameters from AFM images	63
3.5	Continuum models of ion bombarded surface	64
3.6	Sigmund's theory of Sputtering	66
3.7	Linear instability of ion-sputtered surface: Bradley and Harper model . . .	67
3.8	Thermal Surface Diffusion	71
3.9	Makeev, Cuerno and Barabási model	72
3.9.1	Linear regime: below t_c	74
3.9.2	Nonlinear regime: beyond t_c	75
3.10	Asymptotic behavior of ion-bombarded surface	77
3.11	Morphological Phase Diagram	77
3.12	Hydrodynamic theory based model	79
3.13	Shadowing Effect	81
3.14	The Monte Carlo simulation package SRIM	83
4	Experimental investigation on the ripple pattern morphology on Si induced by medium energy Ar ion bombardment	85
4.1	Introduction	86
4.2	Part I. Study of 60 keV Ar-ion-induced ripple pattern on Si(100)	87

4.2.1	Experimental	87
4.2.2	Results	88
4.2.3	Discussion	95
4.3	Part II. Coarsening of surface ripples on Si by 30 keV Ar ion bombardment.	102
4.3.1	Motivation	102
4.3.2	Experimental	103
4.3.3	Results	103
4.3.4	Discussion	112
4.3.5	A brief comparison of our results with some recent experimental works	116
4.4	Conclusion	117
5	Compositional heterogeneity of medium energy Ar ion induced silicon surface ripples	119
5.1	Introduction	120
5.2	Experimental	121
5.3	Results	122
5.3.1	Morphology	122
5.3.2	Composition: EDS study	123
5.4	Discussion	128
5.5	Conclusions	131
6	Photoluminescence from amorphous silicon nanostructure formed by medium keV Ar ion bombardment	132
6.1	Introduction	133
6.2	Experimental	134
6.3	Results	134
6.4	Discussion	139
6.5	Conclusion	141
7	Summary and Outlook	142

A	Measurement of sample temperature during Ar ion bombardment	146
B	Estimation of a , σ and μ	149
C	Determination of penetration depth and areal density of 60 keV Ar in Si	151