## Atomic Force Microscopy beyond topography and electrochemical analysis: Graphene, Zinc Oxide and Bacteria

By

## **Anuradha Bhattacharya**

PHYS05200804005

Saha Institute Of Nuclear Physics, Kolkata

A thesis submitted to the

**Board of Studies in Physical Sciences** 

In partial fulfillment of requirements for the Degree of

**DOCTOR OF PHILOSOPHY** of

HOMI BHABHA NATIONAL INSTITUTE



## **CONTENTS**

Synopsis	9
1. Chapter 1: Introduction	13
1.1 Structural conformations of graphene: Mother of all carbon forms	15
1.1.2 Electronic properties of graphene	18
1.2 Synthesis of graphene	20
1.2.1 Exfoliation using scotch tape	20
1.2.2 Unzipping of CNTs	22
1.2.3 Chemical Exfoliation	22
1.2.4 Supercritical CO2 method	23
1.2.5 Annealing graphite in oxygen rich atmosphere	23
1.2.6 Solvothermal Route	23
1.2.7 Chemical Route	24
1.2.8 Chemical Vapour Deposition	25
1.2.9 Sublimation (SiC)	25
1.3 Wetting property of graphene in relation to its electronic property	26
1.4 Wrinkles in graphene sheet	27
1.5 Magnetic and bio-sensing properties of graphene	28
1.6 Biosensors	29
1.7 Conclusion	31

## 2. Chapter 2: Experimental Methods

2.1 Introduction	38
2.1.1 Sample preparation	38
2.2 Experimental techniques	42
2.21 Contact mode of operation	43
2.2.2 Tapping Mode	45
2.2.3 Frictional Force Microscopy	45
2.2.4 Ultrasonic Force Microscopy (UFM) /	
Atomic Force Acoustic Microscopy (AFAM)	50
2.2.5 Conducting tip AFM	51
2.3.1 Electrochemistry	52
2.3.2 Potentiostat	53
2.3.3 Galvanostat	53
2.3.4 Reference Electrode	53
2.3.4.1 Ag/AgCl reference elecrode	54
2.3.4.2 Calomel reference electrode	55
2.3.5 Counter Electrode	55
2.3.5.1 Platinum counter Electrode	55
2.3.6 Working Electrode	56
2.3.7 Faraday's Law	56
2.3.9 Electrochemical Workstation	57
2.3.9.1 Cyclic Voltammogram	57

2.3.9.2 Amperometric Response	58
2.3.9.3 Electrochemical Impedance Spectoscopy	58
2.4 Basic principle of RAMAN spectroscopy	59
2.5 Basic principle of SQUID magnetometer	59
3. Chapter 3: Development of Biosensors	
3.1 Introduction	63
3.2 Functions of nanomaterials in biosensors	63
3.3 Trends in glucose biosensing : Brief Introduction	63
3.4 Experimental Details	67
3.5 Results and discussions	68
3.6 Graphene as Hydrogen Peroxide Sensor	71
3.6.1 Experiment	73
3.7 Conclusion	77
4. Chapter 4: Physical Properties of wrinkled graphene surfaces	
4.1 Introduction: Graphene – Nucleobase Interactions	80
4.2 Results and Discussions	82
4.3 Conclusion	85
5. Chapter 5: Wetting Property of the Edges of Monoatomic Step on	
Graphite:	
Frictional-Force Microscopy	
5.1 Introduction: Study of wetting property of graphene using FFM	88
5.2 Experimental Details	89

5.3 Conclusions	95
6. Chapter 6: Identifying bacterial fragments using Ultrasonic-A	<b>JFM</b>
6.1 Introduction: Ultrasonic AFM imaging of bacterial cells	98
6.2 Experimental Section	100
6.3 Results and discussions	101
6.4 Conclusion	103
7. Chapter 7: Conclusions	
7.1 Conclusion and future scope	106