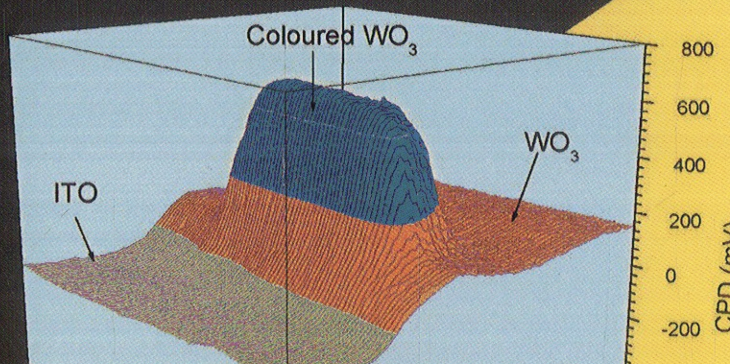
Kelvin Probe for Surface Engineering

Fundamentals and Design



CRC Press
Taylor & Francis Group

A Subrahmanyam
C Suresh Kumar

Contents

Preface vii
Biography of Lord Kelvin ix
Acronyms/Abbreviation xv
Symbols Used xvii

Chapter 1: Introduction to Surfaces and Interfaces **1-20**

1.1 Introduction 1
1.2 Basics of Surfaces and Surface Science 3
1.3 The Structure of Surfaces 4
1.4 The Ionization Energy and Heat of Formation in Surfaces 6
  1.4.1 Ionization Energy 6
  1.4.2 Heat of Formation 6
1.5 Mobility of Atoms on the Surface 6
1.6 Surface Band Structure and Surface States 7
1.7 Interaction of Adsorbed Species and Adsorbate-Induced Changes in Surface Electronic Properties 9
  1.7.1 Monovalent Adatom 10
1.8 Adsorbate-induced Work Function Changes 11
1.9 An Outline of Surface Characterization Techniques 13
1.10 Experimental Techniques for Surface Structure Evaluation 14
1.11 Chemical Composition and Bonding 14
1.12 Electronic and Optical Properties 15
1.13 Kelvin Probe Applied to Surface Studies 18
1.14 A Brief Record and Versatility of Kelvin Probe 18

Chapter 2: The Thermodynamics of Surfaces and Definition of Work Function and Measurement **21-44**

2.1. Introduction to Thermodynamics of Charges on the Surfaces 21
2.2. Chemcial Potential and Contact Potential Difference 22

- 2.2.1 Surface Energy 22
- 2.2.2 Chemical Potential 24

2.3 Chemical Potential of Few-electron System or Atomic Chemical Potential 26

2.4 Fermi Energy and Chemical Potential in Semiconductors 27

2.5 Electrochemical Potential 29

2.6 Electrochemical Potential Distribution with Electrical Current and Temperature Distribution 30

2.7 Definition of Work Function 30
- 2.7.1 Work Function Based on Electro-chemical Potential 30
- 2.7.2 Work Function Based on Contact Potential Difference 32
- 2.7.3 Work Function Based on Thermionic / Field Emission 32
- 2.7.4 Note on the Diversity of Work Function 32

2.8 Work Function: Band Model 33

2.9 The Vacuum Level 33

2.10 Negative Work Function 34

2.11 Surface and Bulk Work Function of Metals and Semiconductors 35
- 2.11.1 Work Function Measurements Based upon Diode Method 35
- 2.11.2 Field Emission Technique of Measuring Work Function 36
- 2.11.3 Photoelectric Method of Measuring Work Function 37

2.12 Contact potential Difference : Metal-Metal System 38

2.13 Principle of Measuring CPD 40
- 2.13.1 Metal–semiconductor System 41

2.14 Non-uniformity of Real Surface and Averaging of the Kelvin Probe 42

2.15 Anisotropy of the Work Function 42

Chapter 3: Design of the Kelvin Probe and the Methods of Measurement of Contact Potential Difference (CPD) 45-82

3.1 Introduction 45

3.2 The Design Aspects of the Kelvin Probe: The Vibrating Capacitor 47
- 3.2.1 Ideal Parallel Plate Capacitor Geometry 47
- 3.2.2 Effect of Fringe Field and Non-parallelism 49
- 3.2.3 Stray Capacitance Effect 51
- 3.2.4 Non-uniformity of Work Function 51

3.3 The Modulation Methods and Noise Reduction Techniques: An Outline of Literature 51

3.4 Kelvin Probe Design 52
- 3.4.1 Kelvin Probe Head Mechanical Design 53
- 3.4.2 Vibration Characteristics of the Probe 53

3.5 Description of the Measuring Circuit 57
  3.5.1 Conversion of the Displacement Current of Vibrating Capacitor into Voltage 57
  3.5.2 The Preamplifier 59
  3.5.3 Analysis of the Preamplifier Output 60
  3.5.4 Harmonic Content of the Output Signal 62
3.6 Method of CPD Measurement 67
  3.6.1 Off-null Method 67
  3.6.2 Feed Back Loop System 68
  3.6.3 Effect of Noise 70
3.7 Spacing Dependence of CPD 71
3.8 The Reference Electrode 73
3.9 Vacuum System 74
3.10 Description of the Sample Holder 75
3.11 Scanning Kelvin Probe 75
  3.11.1 Electrochromic Properties of Tungsten Oxide 78
  3.11.2 Electrical Potential Gradient in the Presence of Local Electric Current 80

Chapter 4: Photo-Emission Yield Spectroscopy(PEYS) 83-110

4.1 Introduction 83
4.2 Basics of Photoemission from Solids 84
  4.2.1 Photoelectric Work Function 84
  4.2.2 Photoemission Process 85
  4.2.3 Experimental Techniques Based on Photoemission 86
4.3 Fowler's Theory of Threshold Photoemission from Metals 86
4.4 Band Structure Approach to Ionization Energy of Semiconductor Surfaces 87
4.5 Measurement of Photoelectric Threshold 89
  4.5.1 Experimental Set up 89
  4.5.2 Measurement Procedure 91
  4.5.3 Types of Samples 92
  4.5.4 Preparation of Reference Electrode in PEYS Experiments 93
4.6 Studies on Metallic Surfaces 93
  4.6.1 Gold Thin Film 94
  4.6.2 Gold Foil 97
  4.6.3 Silver Thin Film 99
  4.6.4 Molybdenum Thin Film 101
  4.6.5 Reference Electrode Work Function : Graphite 104
  4.6.6 Studies on GaAs (100) Surfaces 106

Chapter 5: Surface Photovoltage (SPV) Spetroscopy of Semiconductor Surfaces **111-142**

5.1 Introduction 111
5.2 A Brief Literature on SPV Technique 112
5.3 Basics of Surface Photovoltage Spectroscopy 113
5.4 An Outline of the Relations between the Excess Charge (Δp) and SPV 114
  5.4.1 Super-band Gap SPV 116
  5.4.2 Sub-band Gap SPV 116
  5.4.3 Principle of SPV Measurement Using Kelvin Probe 118
5.5 Surface Photovoltage Experimental Setup 119
  5.5.1 Samples for SPV Measurement 120
5.6 Results 121
  5.6.1 Super-band Gap SPV in GaAs, CdS and CdTe/Silicon Heterojunction 121
  5.6.2 Moderately Doped *n*-type GaAs (100) Surfaces 122
  5.6.3 Heavily Doped *p*-GaAs (100) Surfaces 130
  5.6.4 Semi-insulating GaAs (100) Surfaces 133
  5.6.5 GaAs *p*-*n* Junction 137

APPENDICES **143-158**

Appendix I Surface States in Semiconductors 143
Appendix II The Fourier Coefficients of $C_K(t)$ 147
Appendix III Specifications of Low Power FET –input Electrometer Grade Op Amp AD515AJ 153
Appendix IV Theory of Large-Signal Surface Photovoltage 154

References 159-180
Index 181-182