

Contents

| | |
|--|------|
| Abstract | i |
| List of Abbreviations | iii |
| List of Symbols | v |
| List of Tables | vii |
| List of Figures | viii |
| Flow Chart | xv |
| | |
| 1. Introduction | 1 |
| 1.1 Semi-conducting metal oxide (SMO) nano-structures | 1 |
| 1.1.1 Copper oxide nano-structures | 2 |
| 1.1.2 Zinc oxide nano-structures | 2 |
| 1.2 Impact of Carbon monoxide (CO) on human health | 3 |
| 1.3 Impact of Ethanol vapour | 4 |
| 1.4 SMO nano-structures based gas sensors | 5 |
| 1.4.1 SMO nano-structures based CO sensors | 6 |
| 1.4.2 Recent gaps and possible approaches | 7 |
| 1.5 SMO nano-structures based photo-catalyst | 9 |
| 1.6 Gas sensing mechanism | 10 |
| 1.6.1 Basic characteristics of gas sensor | 14 |
| 1.7. Photo-Catalytic Dye Degradation Process | 15 |
| 1.8 Outline of the work | 17 |
| Bibliography | 18 |
| | |
| 2. Thin Film Deposition and Characterization Techniques | 24 |
| 2.1 Introduction | 24 |
| 2.2 Thin film deposition techniques | 25 |
| 2.2.1 Physical Vapor Deposition | 26 |
| 2.2.1.1 Thermal evaporation technique | 27 |

| | |
|---|-----------|
| 2.2.1.2 DC/RF Magnetron sputtering | 28 |
| 2.3 Characterization of metal oxide thin films | 29 |
| 2.3.1 X-ray diffraction (XRD) | 30 |
| 2.3.2 Field Emission Scanning electron microscope (FESEM) | 32 |
| 2.3.3 Transmission electron microscope (TEM) | 33 |
| 2.3.4 Scanning tunneling microscope (STM) | 35 |
| 2.3.5 Atomic force microscope (AFM) | 37 |
| 2.3.6 UV-VIS Spectroscopy | 38 |
| 2.3.7 Raman Spectroscopy | 40 |
| 2.3.8 X-ray Photoelectron Microscopy (XPS) | 42 |
| 2.3.9 Four Probe Resistivity Measurements | 44 |
| 2.3.10 Gas Sensor set-up | 47 |
| 2.3.11 Photo- catalytic activity | 49 |
| Bibliography | 51 |
| 3. Copper Oxide Thin Films: Growth Mechanism, Properties and Applications towards Catalyst and Sensors | 54 |
| 3.1 Introduction | 56 |
| 3.2 Experimental Details | 59 |
| 3.3 Results and Discussion | 60 |
| 3.3.1 Oxidation Process of Thin Copper Films | 61 |
| 3.3.1.1 Initial oxidation | 61 |
| 3.3.1.2 Temperature dependent oxide phases and role of Thermodynamics | 63 |
| 3.3.1.3 Effect of diffusion kinetics | 69 |
| 3.3.1.4 Interplay between surface kinetic and thermodynamics | 74 |
| 3.3.1.5 Effect of oxygen partial pressure | 75 |
| 3.3.1.6 Effect of crystallographic orientations | 77 |
| 3.3.1.7 Surface oxidation mechanism | 77 |
| 3.3.2 Properties of Copper Oxide thin films | 79 |
| 3.3.2.1 Surface morphology of thin Cu oxide films | 79 |
| Scanning electron microscope (SEM) | 79 |

| | |
|--|-----|
| Atomic force microscope (AFM) | 84 |
| Scanning tunneling microscope (STM) | 85 |
| 3.3.2.2 Optical properties of thin Cu oxides films | 86 |
| Raman Spectroscopy | 86 |
| UV-VIS Spectroscopy | 88 |
| 3.3.2.3 Chemical properties of thin Cu oxide films | 90 |
| X-ray photoelectron microscopy (XPS) | 90 |
| Energy dispersive spectroscopy (EDS) | 96 |
| 3.3.2.4 Electrical Characterization | 97 |
| Four Probe Resistivity measurements | 97 |
| Hall Effect | 102 |
| 3.4 Applications of Copper Oxide Thin Films | 103 |
| 3.4.1 Photo catalytic Activity of Cu ₂ O thin film | 103 |
| 3.4.2 CO sensing of CuO thin films | 106 |
| 3.5 Summary | 113 |
| Bibliography | 115 |
| 4. Zinc Oxide Thin Films: Nano-structures Formation, Properties and Gas Sensing Application | 120 |
| 4.1 Introduction | 122 |
| 4.2 Experimental Details | 124 |
| 4.3 Results and Discussion | 125 |
| 4.3.1 Thermal oxidation process of thin zinc films | 125 |
| 4.3.1.1 Initial oxidation | 126 |
| 4.3.1.2 Temperature dependent oxidation and role of Thermodynamics | 127 |
| 4.3.1.3 Effect of duration and role of diffusion kinetics | 129 |
| 4.3.2 Characterization of ZnO thin films | 130 |
| 4.3.2.1 Scanning electron microscopy (SEM) | 131 |
| 4.3.2.2 Transmission electron microscope (TEM) | 135 |
| 4.3.2.3 Raman Spectroscopy | 138 |
| 4.3.2.4 X-ray photoelectron microscopy (XPS) | 139 |
| 4.3.2.5 Four Probe measurements | 143 |

| | |
|---|-----|
| Four Probe Resistivity measurements | 143 |
| Hall Effect | 144 |
| 4.4 Gas sensing of nano-structured ZnO thin films | 146 |
| 4.4.1 CO gas sensing | 147 |
| 4.4.2 Ethanol vapors sensing | 151 |
| 4.5 Summary | 153 |
| Bibliography | 155 |
| 5. Growth and Characterization of Mixed Oxides (CuO-ZnO) Thin Films and Nano-particles | 160 |
| 5.1 Introduction | 161 |
| 5.2 Experimental Details | 163 |
| 5.3 Results and Discussion | 164 |
| 5.3.1 X-ray diffraction (XRD) | 164 |
| 5.3.2 Scanning electron microscope (SEM) | 168 |
| 5.3.3 UV-Vis spectroscopy | 171 |
| 5.3.4 Raman Spectroscopy | 173 |
| 5.3.5 X-ray photoelectron microscopy (XPS) | 174 |
| 5.4 Summary | 177 |
| Bibliography | 178 |
| 6: Conclusion | 180 |
| 6.1 Summary of Results | 180 |
| 6.2 Further Research Plans | 184 |
| List of Publications | 186 |
| Curriculum Vitae | 188 |