

## **Table of Contents**

|   |                |
|---|----------------|
| <b>List of Figures</b>  | <b>xv</b>      |
| <b>List of Tables</b>   | <b>xxiii</b>   |
| <b>List of Abbreviations</b>  | <b>xxiv</b>    |
| <b>Preface</b>  | <b>xxvi</b>    |
| <br>  |                |
| <b>Chapter 1: Introduction and Literature review</b>                              | <b>(1-37)</b>  |
| 1.1 Biomaterials  | 2              |
| 1.2 What factors led to using Transition Metal substitution for various bioglass? | 9              |
| 1.3 Bioactive Materials   | 10             |
| 1.3.1 Material selection criteria for biomedical applications                     | 11             |
| 1.3.2 Solution employed to assess in vitro bioactivity (SBF)                      | 12             |
| 1.3.3 Hydroxyapatite  | 14             |
| 1.3.4 Bioactive Glasses   | 15             |
| 1.3.5 45S5, 1393 and 1393B3 bioactive glass                                       | 19             |
| 1.3.6 Borosilicate Glass  | 24             |
| 1.3.7 Structure of silicate glasses   | 25             |
| 1.4 Objective of this work  | 28             |
| References  | 30             |
| <br>  |                |
| <b>Chapter 2: Material, Methodology and Characterization Techniques</b>           | <b>(38-67)</b> |
| 2.1 Overview  | 39             |
| 2.2 Materials and Method  | 39             |
| 2.2.1 Materials Preparation   | 40             |
| 2.2.1.1 Melting   | 42             |
| 2.2.1.2 Annealing   | 43             |
| 2.2.1.3 Granulation and pellet processing   | 43             |
| 2.3 Materials Characterization techniques   | 44             |
| 2.3.1 Physical Properties (Measurement of Density)                                | 45             |
| 2.3.2 Chemical Properties (pH Measurement)  | 46             |
| 2.3.3 Mechanical Properties   | 47             |
| 2.3.4 Thermal analysis (TGA-DSC)  | 49             |

|         |   |    |
|---------|---|----|
| 2.3.5   | Electrical Property Analysis (Dielectric Measurement) | 50 |
| 2.3.6   | In vitro bioactivity studies                          | 52 |
| 2.3.6.1 | Phase Formation and Crystal Structure Studies by XRD  | 55 |
| 2.3.6.2 | Fourier Transform Infrared Spectroscopy (FTIR)        | 56 |
| 2.3.6.3 | Scanning Electron Microscope (SEM)                    | 59 |
| 2.3.6.4 | Energy dispersive X-ray spectroscopy (EDS) analysis   | 60 |
| 2.3.6.5 | Atomic Force Microscopy (AFM) analysis                | 61 |
| 2.3.7   | Biological Evaluation                                 | 61 |
| 2.3.7.1 | Cell culture process                                  | 61 |
| 2.3.7.2 | Phase Contrast Imaging                                | 63 |
| 2.3.8   | Hemocompatibility                                     | 64 |
|         | References  | 66 |

### **Chapter 3: Study bioactivity of V<sub>2</sub>O<sub>5</sub> substituted Borosilicate glass system (68-94)**

|       |  |    |
|-------|--|----|
| 3.1   | Introduction                                 | 69 |
| 3.2   | Experimental procedure                       | 70 |
| 3.3   | Characterization                             | 71 |
| 3.3.1 | Physical, chemical and Mechanical Properties | 71 |
| 3.3.2 | The <i>in-vitro</i> bioactivity analysis     | 72 |
| 3.3.3 | <i>In-vitro</i> Hemocompatibility            | 74 |
| 3.3.4 | Cellular Compatibility                       | 75 |
| 3.3.5 | Electrical Property                          | 76 |
| 3.4   | Results and Discussion                       | 78 |
| 3.4.1 | Physical, Chemical and Mechanical Properties | 78 |
| 3.4.2 | XRD Phase analysis                           | 79 |
| 3.4.3 | FTIR Transmittance Analysis                  | 80 |
| 3.4.4 | SEM and EDX analysis                         | 81 |
| 3.4.5 | <i>In-vitro</i> Hemocompatibility            | 84 |
| 3.4.6 | The <i>In-vitro</i> Cellular Analysis        | 85 |
| 3.4.7 | Electrical Properties                        | 86 |
| 3.5   | Summary                                      | 89 |
|       | References                                   | 90 |

|  |                  |
|--|------------------|
| <b>Chapter 4: Study bioactivity of V<sub>2</sub>O<sub>5</sub> substituted 1393-B3 Borate glass</b> | <b>(95-105)</b>  |
| 4.1 Introduction   | 96               |
| 4.2 Experimental details   | 96               |
| 4.2.1 <i>In-vitro</i> Bioactivity  | 97               |
| 4.2.2 Hemocompatibility  | 98               |
| 4.2.3 Biological Characterization  | 98               |
| 4.3 Results and Discussion   | 99               |
| 4.3.1 <i>In-vitro</i> analysis   | 99               |
| 4.3.2 Hemocompatibility  | 102              |
| 4.3.3 In Vitro Cellular Analysis   | 102              |
| 4.4 Summary  | 103              |
| References   | 104              |
| <br>   |                  |
| <b>Chapter 5: Study of bioactivity of TiO<sub>2</sub> substituted 1393-B3 Borate glass</b>         | <b>(106-134)</b> |
| 5.1 Introduction   | 107              |
| 5.2 Materials and methods  | 108              |
| 5.2.1 Synthesis of bioglass  | 108              |
| 5.2.2 Physico-chemical, mechanical and thermal properties  | 110              |
| 5.2.2.1 Physico-chemical properties  | 110              |
| 5.2.2.2 Mechanical properties  | 111              |
| 5.2.2.3 Thermal properties   | 112              |
| 5.2.3 <i>In-vitro</i> analysis   | 113              |
| 5.2.3.1 Phase, functional group and surface morphology study                                       | 113              |
| 5.2.4 Hemocompatibility  | 113              |
| 5.2.5 <i>In-vitro</i> cellular analysis  | 114              |
| 5.3 Result and discussion  | 116              |
| 5.3.1 Physico-chemical, thermal and mechanical properties  | 116              |
| 5.3.1.1 Physico-chemical properties  | 116              |
| 5.3.1.2 Mechanical Properties  | 117              |
| 5.3.1.3 Thermal Properties   | 119              |
| 5.3.2 <i>In-vitro</i> analysis   | 120              |
| 5.3.2.1 FTIR spectroscopy analysis   | 120              |
| 5.3.2.2 XRD analysis   | 121              |

|         |                                   |     |
|---------|-----------------------------------|-----|
| 5.3.2.3 | SEM-EDS analysis                  | 124 |
| 5.3.3   | Hemocompatibility                 | 125 |
| 5.3.4   | <i>In-vitro</i> cellular analysis | 126 |
| 5.3.4.1 | Cellular compatibility assay      | 126 |
| 5.3.4.2 | Phase-contrast Imaging            | 127 |
| 5.4     | Summary                           | 127 |
|         | References                        | 128 |

## **Chapter 6: Study of bioactivity of ZrO<sub>2</sub> substituted 1393-B3 Borate glass (135-160)**

|         |   |     |
|---------|---|-----|
| 6.1     | Introduction  | 136 |
| 6.2     | Materials and Methods                                       | 137 |
| 6.2.1   | Glass samples synthesis                                     | 137 |
| 6.2.2   | Physico-chemical, thermal and mechanical properties         | 138 |
| 6.2.2.1 | Physico-chemical properties                                 | 138 |
| 6.2.2.2 | Thermal properties  | 139 |
| 6.2.2.3 | Mechanical properties                                       | 139 |
| 6.2.3   | <i>In-vitro</i> characterization                            | 140 |
| 6.2.3.1 | FTIR spectroscopy analysis                                  | 141 |
| 6.2.3.2 | XRD analysis  | 141 |
| 6.2.3.3 | SEM-EDS   | 141 |
| 6.2.4   | <i>In-vitro</i> hemocompatibility                           | 141 |
| 6.2.5   | Cellular compatibility                                      | 142 |
| 6.3     | Result and Discussion                                       | 143 |
| 6.3.1   | Physico-chemical, thermal, and mechanical property analysis | 143 |
| 6.3.1.1 | Physico-chemical properties                                 | 143 |
| 6.3.1.2 | Thermal properties  | 145 |
| 6.3.1.3 | Mechanical properties                                       | 146 |
| 6.3.2   | <i>In-vitro</i> analysis                                    | 147 |
| 6.3.2.1 | FTIR analysis   | 147 |
| 6.3.2.2 | Crystallographic Analysis                                   | 149 |
| 6.3.2.3 | Surface morphology and elemental analysis                   | 151 |
| 6.3.3   | Hemocompatibility   | 152 |
| 6.3.4   | <i>In-vitro</i> cellular analysis                           | 154 |

|         |                              |     |
|---------|------------------------------|-----|
| 6.3.4.1 | Cellular compatibility assay | 154 |
| 6.3.4.2 | Phase-contrast Imaging       | 154 |
| 6.4     | Summary                      | 154 |
|         | References                   | 156 |

## **Chapter 7: Study of bioactivity of ZnO substituted 45S5 glass after polarization (161-183)**

|         |  |     |
|---------|--|-----|
| 7.1     | Introduction   | 162 |
| 7.2     | Materials and Methods                                  | 164 |
| 7.2.1   | Glass Sample Synthesis                                 | 164 |
| 7.2.2   | Testing and Characterization                           | 165 |
| 7.2.2.1 | DTA  | 165 |
| 7.2.2.2 | XRD  | 165 |
| 7.2.2.3 | FTIR   | 165 |
| 7.2.2.4 | SEM-EDS  | 165 |
| 7.2.2.5 | AFM  | 166 |
| 7.2.3   | <i>In-vitro</i> analysis (Biological Characterization) | 166 |
| 7.2.4   | AC conductivity and Dielectric analysis                | 166 |
| 7.2.5   | Electrical Polarization                                | 167 |
| 7.3     | Result and Discussion                                  | 168 |
| 7.3.1   | Thermal Properties                                     | 168 |
| 7.3.2   | Mechanical Properties                                  | 168 |
| 7.3.3   | <i>In-vitro</i> bioactivity analysis                   | 169 |
| 7.3.3.1 | FTIR   | 170 |
| 7.3.3.2 | XRD  | 171 |
| 7.3.3.3 | SEM and EDS analysis                                   | 173 |
| 7.3.3.4 | AFM analysis   | 175 |
| 7.3.4   | Dielectric and AC conductivity analysis                | 177 |
| 7.4     | Summary  | 178 |
|         | References   | 179 |

|   |                  |
|---|------------------|
| <b>Chapter 8: Conclusion and Future Scope</b> | <b>(184-188)</b> |
| 8.1 Summary                                   | 185              |
| 8.2 Future Scope of the present work          | 187              |
| <b>List of Publications</b>                   | 189              |