3

Contents

| | riciace Al |
|-------|--|
| 1 | Background of Uranium Chemistry 1 |
| 1.1 | Introduction of Uranium in Nuclear Industry 1 |
| 1.1.1 | Importance of Uranium Resource in Nuclear Industry 1 |
| 1.1.2 | Uranium Cycle in Nuclear Industry 2 |
| 1.2 | Coordination and Species of Uranium 2 |
| 1.2.1 | General Chemical Properties of Uranium 2 |
| 1.2.2 | Basic Uranium Species in the Solution-Uranyl and Uranyl Compound |
| 1.2.3 | Valence Transformation of Uranium 4 |
| | References 5 |
| | |
| 2 | Introduction of Uranium Reduction Extraction 9 |
| 2.1 | Introduction of Uranium Extraction 9 |
| 2.2 | Introduction of Uranium Reduction Extraction 9 |
| 2.2.1 | Basic Concept and Process of Uranium Reduction Extraction 9 |
| 2.2.2 | Uranium Reduction by Zerovalent Iron 10 |
| 2.2.3 | Photochemistry and Photochemical Uranium Reduction 10 |
| 2.2.4 | Electrochemistry Involved in the Electrochemical Uranium |
| | Reduction 11 |
| 2.3 | Key Factors to Influence the Uranium Reduction Extraction 11 |
| 2.3.1 | Surface Adsorption and Coordination 12 |
| 2.3.2 | Reductive Ability 12 |
| 2.4 | Practical Situation that Requires Uranium Extraction 13 |
| 2.4.1 | Uranium Extraction in Seawater 13 |
| 2.4.2 | Uranium Extraction in Mining and Metallurgy 13 |
| 2.4.3 | Uranium Extraction in Nuclear Wastewater 14 |
| | References 14 |
| 3 | Uranium Reduction Extraction by Modified Nano Zerovalent |
| | Iron 19 |
| 3.1 | Introduction of Nano Zerovalent Iron 19 |
| 3.2 | Material Design for Promoted Stability and Reductive Ability 21 |



| vi | Contents | |
|----|-------------|---|
| | 3.3 | Uranium Extraction Performance 24 |
| | 3.4 | Reaction Mechanism 26 |
| | 3.5 | Conclusion and Future Perspectives 29 |
| | | References 30 |
| | 4 | Uranium Reduction Extraction by Commercial Iron |
| | | Powder 33 |
| | 4.1 | Introduction of Alternative Abundant Reductant-Commercial Iron |
| | 4.0 | Powder 33 |
| | 4.2 | Ultrasound Enhancement of Uranium Extraction by Commercial Iron |
| | 404 | Powder 34 |
| | 4.2.1 | Extraction of U(VI) by Commercial Iron Powder 34 |
| | 4.2.2 | Analysis of Uranium Enrichment Status 36 |
| | 4.2.3 | Key Mechanism of Ultrasonic Enhanced Commercial Iron Powder for Uranium Extraction 36 |
| | 4.3 | Microbial Sulfurization-Enhanced Commercial Iron Powder Extraction |
| | 4.3 | of Uranium 39 |
| | 4.3.1 | Characterizations of BS-ZVI 39 |
| | 4.3.2 | Performance of Photocatalytic Enrichment of U(VI) by BS-ZVI 40 |
| | 4.3.3 | Photoelectric Properties and Energy Band Structure of BS-ZVI 41 |
| | 4.3.4 | Photocatalytic Enrichment Mechanism of U(VI) 43 |
| | 4.4 | Conclusion and Perspectives 45 |
| | ••• | References 45 |
| | 5 | Photocatalytic Uranium Reduction Extraction |
| | J | by Carbon-Semiconductor Hybrid Material 49 |
| | 5.1 | Introduction of Photocatalytic Uranium Reduction Extraction 49 |
| | 5.2 | Motivated Material Design of Carbon-Semiconductor Hybrid |
| | J,2 | Material 51 |
| | 5.2.1 | Introduction 51 |
| | 5.2.2 | Results and Discussions 52 |
| | 5.2.3 | Summary 57 |
| | 5.3 | Band Engineering of Carbon-Semiconductor Hybrid Material 57 |
| | 5.3.1 | Introduction 57 |
| | 5.3.2 | Results and Discussions 58 |
| | 5.3.3 | Summary 64 |
| | 5.4 | Assembly of Carbon-Semiconductor Hybrid Material for Facile Recycle |
| | <i>5.</i> . | Use 65 |
| | 5.4.1 | Introduction 65 |
| | 5.4.2 | Results and Discussions 66 |
| | 5.4.3 | Summary 71 |
| | 5.5 | Conclusion and Perspectives 72 |
| | | References 73 |

| 6 | Photocatalytic Uranium Reduction Extraction by Surface Reconstructed Semiconductor 77 |
|---------|---|
| 6.1 | Introduction 77 |
| 6.2 | Design of Hydrogen-Incorporated Semiconductor-Hydrogen-Assist 78 |
| 6.2.1 | Hydrogen-Incorporated VO ₂ 78 |
| 6.2.2 | Hydrogen-Incorporated Oxidized WS ₂ 86 |
| 6.3 | Hydrogen-Incorporated Vacancy Engineering 92 |
| 6.3.1 | Oxygen Vacancy-Case of WO _{3-x} 92 |
| 6.3.2 | Doping-Induced Cation Vacancy-Case of Fe-Doped TiO ₂ 99 |
| 6.3.3 | Oxygen Vacancy Engineering in Black TiO ₂ @Co ₂ P S-Scheme 104 |
| 6.4 | Conclusions 110 |
| | References 111 |
| 7 | Enhanced Photocatalytic Uranium Reduction Extraction |
| | by Electron Enhancement 117 |
| 7.1 | Introduction 117 |
| 7.2 | Plasmonic Enhancement of Uranium Extraction 117 |
| 7.2.1 | Enhanced Uranium by Hot Electrons of Plasmonic Metals 118 |
| 7.2.1.1 | Introduction 118 |
| 7.2.1.2 | Summary 125 |
| 7.2.2 | Plasmonic Engineering – High-Entropy Plasmonic Alloy 125 |
| 7.2.2.1 | Introduction 125 |
| 7.2.2.2 | Summary 133 |
| 7.2.3 | Promotion of Electron Energy by Upconversion-Case of Er Doping 133 |
| 7.2.3.1 | Introduction 133 |
| 7.2.3.2 | Summary 141 |
| 7.3 | Enhanced by Cocatalysis 143 |
| 7.3.1 | Introduction 143 |
| 7.3.1.1 | Results and Discussions 145 |
| 7.3.2 | Summary 156 |
| 7.4 | Conclusion and Perspectives 157 |
| | References 157 |
| 8 | Photocatalytic Uranium Reduction Extraction in Tributyl Phosphate-Kerosene System 169 |
| 8.1 | Introduction of Tributyl Phosphate-Kerosene System-Spent Fuel |
| | Reprocessing 169 |
| 8.2 | Material Design-Self Oxidation of Red Phosphorus 170 |
| 8.3 | Uranium Extraction in Tributyl Phosphate-Kerosene System 173 |
| 8.4 | Reaction Mechanism-Self Oxidation Cycle 177 |
| 8.5 | Conclusion and Perspectives 181 |
| | References 182 |

| viii Contents | |
|-----------------|--|
|-----------------|--|

| 9 | Photocatalytic Uranium Reduction Extraction |
|--------|--|
| | in Fluoride-Containing System 187 |
| 9.1 | Introduction of Photocatalytic Uranium Reduction Extraction 187 |
| 9.2 | Simultaneously Constructing U(VI) Constraint Sites and Water |
| | Oxidation Sites to Promote the Purification of Fluorine-Containing |
| | Uranium Wastewater 188 |
| 9.2.1 | Introduction 188 |
| 9.2.2 | Results and Discussions 189 |
| 9.2.3 | Summary 197 |
| 9.3 | Advanced Photocatalytic Heterojunction with Plasmon Resonance Effect |
| | for Uranium Extraction from Fluoride-Containing Uranium |
| | Wastewater 198 |
| 9.3.1 | Introduction 198 |
| 9.3.2 | Results and Discussions 199 |
| 9.3.3 | Summary 204 |
| | References 205 |
| 10 | Electrochemical Uranium Reduction Extraction: Design |
| | of Electrode Materials 211 |
| 10.1 | Introduction of Electrocatalytic Uranium Reduction Extraction 211 |
| 10.2 | Edge-Site Confinement for Enhanced Electrocatalytic Uranium |
| | Reduction Extraction 213 |
| 10.2.1 | Introduction 213 |
| 10.2.2 | Results and Discussions 214 |
| 10.2.3 | |
| 10.3 | Facet-Dependent Electrochemical Uranium Extraction in Seawater Over |
| | Fe ₃ O ₄ Catalysts 219 |
| 10.3.1 | Introduction 219 |
| 10.3.2 | Results and Discussions 220 |
| 10.3.3 | Conclusion 225 |
| 10.4 | Heterogeneous Interface-Enhanced Electrocatalytic Uranium Reduction |
| | Extraction 225 |
| 10.4.1 | Introduction 225 |
| 10.4.2 | Results and Discussions 226 |
| 10.4.3 | Summary 231 |
| 10.5 | Surface Hydroxyl-Enhanced Electrochemical Extraction of |
| | Uranium 232 |
| 10.5.1 | Introduction 232 |
| 10.5.2 | Results and Discussions 233 |
| 10.5.3 | Summary 237 |
| 10.6 | Charge-Separation Engineering for Electrocatalytic Uranium Reduction |
| | Extraction 238 |
| 10.6.1 | Introduction 238 |
| 10.6.2 | Results and Discussions 239 |
| 10.6.3 | Summary 244 |
| | |

| 10.7 | Conclusion and Perspectives 244 | |
|--------|---|-----|
| | References 245 | |
| 11 | Electrochemical Uranium Extraction from | |
| | Seawater-Reproduced Vacancy 253 | |
| 11.1 | Introduction of Electrocatalytic Uranium Extraction from Seawater 2 | 253 |
| 11.2 | High-Selective Site Oxygen Vacancy 253 | |
| 11.3 | Conclusion 257 | |
| | References 258 | |
| 12 | Electrochemical Uranium Extraction from Nuclear Wastewater | |
| | of Fuel Production 263 | |
| 12.1 | Introduction of Nuclear Wastewater of Fuel Production: Ultrahigh | |
| | Concentration of Fluoride 263 | |
| 12.2 | Material Design-Ion Pair Sites 264 | |
| 12.3 | Uranium Extraction Performance 266 | |
| 12.3.1 | Simulated Wastewater 266 | |
| 12.3.2 | Real Nuclear Wastewater 268 | |
| 12.4 | Reaction Mechanism - Coordination and Crystallization 268 | |
| 12.5 | Conclusion 270 | |
| | References 270 | |
| 13 | Perspectives and Emerging Directions 273 | |
| 13.1 | Application in Real Situation 273 | |
| 13.2 | Criteria of Performance Evaluation 274 | |
| 13.3 | Device of Uranium Reduction Extraction 276 | |
| 13.3.1 | Chemical Reduction Coupled with External Field 276 | |
| 13.3.2 | Photocatalytic Device for Flow Cell 276 | |
| 13.3.3 | Electrocatalytic Device with Controlling System 277 | |
| | References 279 | |
| | | |

Index 283