



Nanostructures of Transition Metal Sulfides for Anion Exchange Membrane Water Electrolysis

Lu Xia

Energie & Umwelt / Energy & Environment

Band / Volume 597

ISBN 978-3-95806-670-0

Forschungszentrum Jülich GmbH
Institut für Energie- und Klimaforschung
Elektrochemische Verfahrenstechnik (IEK-14)

Nanostructures of Transition Metal Sulfides for Anion Exchange Membrane Water Electrolysis

Lu Xia

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 597

ISSN 1866-1793

ISBN 978-3-95806-670-0

1	Introduction and highlights of the work	1
1.1	State of the art.....	1
1.2	Research progress and bottlenecks	1
1.2.1	Classification of water electrolysis systems	1
1.2.2	Alkaline water electrolysis (AWE).....	2
1.2.3	Proton exchange membrane water electrolysis (PEMWE).....	3
1.2.4	Anion exchange membrane water electrolysis (AEMWE).....	4
1.3	Basic knowledge of AEMWE	4
1.3.1	Configuration of AEMWE system	4
1.3.2	Single cell configuration.....	6
1.3.3	Thermodynamics and kinetics	7
1.3.4	Membrane electrode assembly (MEA).....	9
1.3.5	Hydrogen evolution reaction (HER).....	10
1.3.6	Oxygen evolution reaction (OER).....	11
1.4	Developments of OER catalysts in AEMWE.....	12
1.4.1	Catalysts for AEMWE	12
1.4.2	Transition metal sulfides (TMS) as OER catalysts.....	14
1.4.3	Advantages, challenges and strategies of TMS	14
1.5	Highlights of the thesis	16
1.6	Outline of the thesis.....	17
2	Experimental methods for NiS _x	19
2.1	Chemicals and materials.....	19
2.2	Catalyst synthesis	19
2.3	Materials characterizations	20
2.3.1	X-ray diffraction (XRD).....	20
2.3.2	Scanning electron microscope (SEM)	23
2.3.3	Transmission Electron Microscopy (TEM).....	25
2.3.4	X-ray photoelectron spectroscopy (XPS)	27
2.3.5	Fourier transform infrared spectroscopy (FTIR)	28
2.4	Half-cell tests.....	29

2.5	Materials for single-cell tests.....	30
2.6	Electrode fabrication via CCS	31
2.7	Full-cell configuration	33
2.8	Full-cell testing steps	35
3	Experimental methods for $\text{Ni}_x\text{Fe}_{1-x}\text{S}_2$	36
3.1	Chemicals	36
3.2	Synthesis of $\text{Ni}_x\text{Fe}_{1-x}\text{S}_2$	37
3.3	Material characterizations.....	38
3.3.1	Basic XRD, SEM, HRTEM, STEM and XPS	38
3.3.2	Inductively Coupled Plasma with Optical Emission Spectroscopy (ICP-OES)	38
3.3.3	<i>In-situ</i> Raman spectra	39
4	Experimental methods for performance optimization.....	43
4.1	Materials	43
4.2	Electrode preparation.....	43
4.3	Mechanical pressure tests	43
4.4	Physical properties.....	45
4.5	Surface morphology and conductivity.....	46
4.6	Single-cell tests.....	46
5	$\text{NiS}_2/\text{Ni}_3\text{S}_4$ nano-cubes	47
5.0	Preface	47
5.1	Characterizations of $\text{NiS}_2/\text{Ni}_3\text{S}_4$	49
5.1.1	Phase, chemical composition and morphology of $\text{NiS}_2/\text{Ni}_3\text{S}_4$	49
5.1.2	Sulfur leaching of $\text{NiS}_2/\text{Ni}_3\text{S}_4$ in half cells	53
5.2	Cycling stability of $\text{NiS}_2/\text{Ni}_3\text{S}_4$ in the half cell	60
5.3	Long-term stability of $\text{NiS}_2/\text{Ni}_3\text{S}_4$ in half cells.....	68
5.4	Sulfur leaching of $\text{NiS}_2/\text{Ni}_3\text{S}_4$ in full cells.....	70
5.5	Long-term stability of $\text{NiS}_2/\text{Ni}_3\text{S}_4$ in full cells	76
5.6	Summary of $\text{NiS}_2/\text{Ni}_3\text{S}_4$ based catalyst	82
6	$\text{Ni}_{0.67}\text{Fe}_{0.33}\text{S}_2$ nano-octahedrons.....	83
6.0	Preface	83

6.1 Characterizations of Ni _{0.67} Fe _{0.33} S ₂ nano-octahedrons.....	85
6.1.1 Phase, chemical composition and morphology of Ni _x Fe _{1-x} S ₂ (x=0-1).....	85
6.1.2 Sulfur leaching of Ni _x Fe _{1-x} S ₂ (x=0-1) in half cells	93
6.1.3 Activity of Ni _x Fe _{1-x} S ₂ (x=0-1) in half cells.....	96
6.1.4 Stability of Ni _{0.67} Fe _{0.33} S ₂ in half cells	104
6.2 Sulfur leaching of Ni _{0.67} Fe _{0.33} S ₂ in full cells	106
6.3 Long-term stability of Ni _{0.67} Fe _{0.33} S ₂ in full cells.....	106
6.4 Summary of Ni _{0.67} Fe _{0.33} S ₂ based catalyst	111
7 Optimization of single-cell performance.....	113
7.0 Preface	113
7.1 Control and quantification of mechanical pressure	116
7.2 Mechanical pressure effects on physical properties	118
7.3 Mechanical pressure effects on single-cell performance.....	123
7.3.1 Mechanical pressure effects on AF1-HNN5-25 based cells	124
7.3.2 Mechanical pressure effects on AF1-HNN8-50 based cells	126
7.3.3 Mechanical pressure effects on AF2-HWP8-75 based cells.....	128
7.4 Summary of the mechanical pressure effects and recommendations	130
7.5 Performance optimization for Ni _{0.67} Fe _{0.33} S ₂ based cells.....	131
8 Overall discussion	133
9 Conclusion and outlook.....	137
9.1 Conclusion	137
9.2 Outlook	138
10 References	139
11 Appendix	151
12 References in Appendix	155
List of Abbreviations.....	159
Acknowledgements	161

Energie & Umwelt / Energy & Environment
Band / Volume 597
ISBN 978-3-95806-670-0

Mitglied der Helmholtz-Gemeinschaft

