



Masterarbeit

**Analyse zur stapelfehlerenergie-abhängigen
Mikrostrukturentwicklung hochverformter
Legierungen**

**Stacking Fault Energy-dependent Microstructure
Evolution of Severely Deformed Alloys**

Friederike Emeis

Themensteller: Prof. Dr. Gerhard Wilde
Institut für Materialphysik

Contents

1	Introduction	1
2	Theoretical Background	3
2.1	Stacking Fault Energy	3
2.1.1	Dislocations	3
2.1.2	Shockley Partial Dislocations	5
2.2	Grain Boundaries	9
2.2.1	Low-Angle Grain Boundary	9
2.2.2	High-Angle Grain Boundary	9
2.3	Deformation, Recovery and Recrystallization	10
2.3.1	Recovery	10
2.3.2	Recrystallization	11
3	Experimental Methods	13
3.1	High Pressure Torsion (HPT)	13
3.2	Vickers Hardness Measurement	15
3.3	X-Ray Diffraction (XRD)	15
3.3.1	Theory of XRD: Determination of the Lattice Constant	15
3.3.2	Determination of Grain Sizes using XRD	16
3.3.3	Intensity Distribution	16
3.4	Electron Back-Scatter Diffraction (EBSD)	17
3.4.1	Evaluation of the EBSD Measurements	19
3.5	Transmission Electron Microscopy (TEM)	21
3.5.1	Reciprocal Lattice vector (g-vector) and the Diffraction Pattern	21
3.5.2	Dark-Field Image	21
3.5.3	Experimental Determination of the Stacking Fault Energy . .	22
3.6	Sample Preparation	23
3.6.1	Annealing after HPT	24
3.6.2	Elektrropolishing	24

3.6.3 Polishing	24
4 Copper-Nickel Alloys	25
4.1 General Information	25
4.1.1 Suspected Stacking Fault Energies	26
4.1.2 Lattice Constant	27
4.1.3 Elastic stiffness Constants, Anisotropy, Burgers vector and Shear Modulus of the Alloys	36
4.2 Precipitations in the Alloys	37
4.3 Ultrafine Grained Cu ₅₀ Ni ₅₀ -sample	38
4.4 Sample Overview	39
5 Results	41
5.1 Determination of the Stacking Fault Energy	41
5.1.1 Cu ₁₀ Ni ₉₀	41
5.1.2 Cu ₅₀ Ni ₅₀	52
5.2 Light microscope	66
5.3 Hardness	69
5.3.1 As-Cast Samples	70
5.3.2 Annealed Samples	70
5.3.3 High Pressure Samples	70
5.3.4 High Pressure Torsion Samples	71
5.3.5 Subsequent Annealing after HPT	74
5.3.6 Comparison of the Hardness	75
5.4 EBSD	76
5.4.1 HPT	78
5.4.2 Subsequent Annealing after HPT	86
5.5 HPT1 and HPT1/30M/500 of Cu ₁₀ Ni ₉₀	94
5.5.1 Evolution of Grain Sizes	95
5.5.2 Evolution of Subboundaries	100
5.5.3 Evolution of Hardness	103
5.5.4 Grain Size and Hardness	104
6 Discussion	109
6.1 Determination of the Lattice Constants	109
6.2 Determination of the Stacking Fault Energy	110
6.3 Influence of the Stacking Fault Energy on Mechanical Behaviour	111
6.4 Hardness of the Alloys	112

6.4.1	As-Cast	112
6.4.2	Annealed	113
6.4.3	High Pressure Sample	113
6.4.4	Hardness after Severe Deformation and Corresponding Induced True Strain	114
6.4.5	Minimum Grain Sizes	115
6.4.6	Uniformity	115
6.4.7	Difference between HPT5 and HPT10 for the Cu ₁₀ Ni ₉₀ and Cu ₅₀ Ni ₅₀ Alloy	116
6.5	Annealing after HPT: Recovery and Recrystallization	117
6.5.1	2/100	117
6.5.2	2/270	117
6.5.3	30M/500	118
6.5.4	2/500	118
6.5.5	2/700	118
6.5.6	Rate of Recovery	119
6.6	Amount of Annealing Twins	119
6.7	Amount of Mechanical Twins	120
6.8	Cu ₁₀ Ni ₉₀ : HPT1 and HPT1/30M/500 Sample	121
6.8.1	Evolution of Grain Sizes	121
6.8.2	Evolution of Uniformity	121
6.8.3	Evolution of Grain Boundaries	122
6.8.4	Evolution of Hardness	122
6.8.5	Hall-Petch Relation	124
6.9	Influence of As-Cast State on Results	125
6.10	Conclusion	126
A	Appendix	129
A.1	Phase Diagram	129
A.2	Estimation of Experimental Uncertainties	130
A.2.1	Estimation of the Experimental Uncertainty for the SFE	131
A.3	Fitting of the Curves	132
A.3.1	Gauss Fitting	132
A.3.2	Grain Size Fitting	132
A.4	Grain Size Values	133