

# Contents

<b>Nomenclature</b>	<b>iii</b>
<b>1 Introduction</b>	<b>1</b>
<b>I</b>	<b>3</b>
<b>2 Background</b>	<b>4</b>
2.1 Strength of materials and dislocation density . . . . .	4
2.1.1 Statistically stored dislocations . . . . .	9
2.1.2 Geometrically necessary dislocations . . . . .	10
2.2 Plastic anisotropy in metals . . . . .	12
2.2.1 Schmid based single glide model . . . . .	12
2.2.2 Taylor based multiple glide model . . . . .	13
2.2.3 Rate sensitive models . . . . .	14
<b>3 Literature Review</b>	<b>15</b>
3.1 Mechanical size effects in the absence of strain gradients . . . . .	15
3.2 Focussed ion beam milling . . . . .	25
3.3 Indentation size effect . . . . .	26
3.3.1 Self-similar indenter tips . . . . .	26
3.3.2 Spherical indenter tips . . . . .	28
3.4 How to measure GNDs? . . . . .	31
3.5 Effect of crystal orientation during indentation . . . . .	32
3.6 Micro bending . . . . .	33
3.7 Bauschinger effect . . . . .	36

3.8	Few crystal works . . . . .	37
3.9	Dislocation based plasticity models . . . . .	39
3.9.1	Dislocation kinetics . . . . .	40
3.9.2	Mobile dislocation density and its evolution . . . . .	40
3.9.3	Dislocation glide velocity . . . . .	42
3.9.4	Dislocation density based strain hardening . . . . .	42
3.9.5	Dislocation density based grain boundary models . . . . .	43
<b>II</b>		<b>45</b>
<b>4</b>	<b>Finite element models</b>	<b>46</b>
4.1	Balance equations . . . . .	46
4.2	Finite element discretization . . . . .	48
4.3	Isotropic hardening model . . . . .	51
4.3.1	Deformation kinematics . . . . .	51
4.3.2	Dislocation based constitutive law . . . . .	53
4.3.3	Grain boundary model . . . . .	55
4.3.4	Implicit time integration method . . . . .	56
4.4	Crystal plasticity . . . . .	59
4.4.1	Deformation kinematics . . . . .	59
4.4.2	Phenomenological constitutive law . . . . .	62
4.4.3	Dislocation based constitutive law . . . . .	63
4.4.4	Implicit time integration method . . . . .	64
<b>5</b>	<b>Bending of micro cantilever beams with cube orientation</b>	<b>69</b>
5.1	Experiments . . . . .	69
5.2	Experimental results . . . . .	72
5.3	Simulations . . . . .	79
5.3.1	Effects of thickness variation (taper), friction coefficient and radius of the rounded inside corner . . . . .	80
5.3.2	Final model . . . . .	81
5.4	Discussion . . . . .	83

<b>6</b>	<b>Effects of crystal orientation and grain boundary on the plastic strain distributions of a few crystal aluminum</b>	<b>86</b>
6.1	Experiments . . . . .	86
6.2	Simulations . . . . .	92
6.3	Discussion . . . . .	97
<b>7</b>	<b>Experimental investigation of the mechanical size effect observed in cantilever beam bending</b>	<b>99</b>
7.1	Cantilever beams with rectangular cross sections . . . . .	99
7.1.1	Experiments . . . . .	99
7.1.1.1	Fabrication of the beams . . . . .	99
7.1.1.2	Material characterization . . . . .	101
7.1.1.3	Mechanical test results . . . . .	101
7.1.1.4	SEM and EBSD measurements after bending . . . . .	104
7.1.2	Discussion . . . . .	107
7.2	Cantilever beams with circular cross sections . . . . .	111
7.2.1	Experiments . . . . .	112
7.2.2	Discussion . . . . .	114
<b>8</b>	<b>Experimental investigation of Bauschinger effect during bending of a micro cantilever beam</b>	<b>120</b>
8.1	Experiments . . . . .	120
8.2	Discussion . . . . .	123
<b>9</b>	<b>Depth dependence of hardness during <i>conical-like</i> indentation of copper</b>	<b>130</b>
9.1	Experimental . . . . .	130
9.1.1	Indentation . . . . .	130
9.1.2	EBSD measurements . . . . .	131
9.2	Analysis of EBSD data . . . . .	134
9.2.1	GND analysis . . . . .	134
9.2.2	Stress fields around GNDs . . . . .	137
9.3	Results and Discussion . . . . .	140

## CONTENTS

<b>10 Conclusions</b>	<b>145</b>
<b>A Important definitions</b>	<b>150</b>
A.1 Crystal to sample reference transformations . . . . .	150
A.2 Work conjugacy between resolved shear stress and shear rates . .	150
A.3 Perturbation method to find the material tangent . . . . .	152
A.4 Mobile dislocation density . . . . .	153
A.5 Vector and tensor operations . . . . .	153