

# Contents

<b>1</b>	<b>Introduction</b>	1
	References	4
<b>2</b>	<b>Growth of Ultrathin Metal Films</b>	5
2.1	Growth Modes	5
2.2	Thermodynamic Criterion for Growth Modes	7
2.2.1	Surface Free Energy and Interfacial Free Energy	8
2.2.2	Strain Energy and Stranski-Krastanov Growth	12
2.3	Kinetic Aspects and Microscopic Models of Growth	16
2.3.1	Atomistic Processes in Film Growth	17
2.3.2	Kinetic Rate Equations for Nucleation and Growth	21
2.4	Experimental Techniques for Growth Mode Analysis	25
2.4.1	Reflection High-Energy Electron Diffraction (RHEED)	26
2.4.2	Scanning Tunneling Microscopy (STM)	29
2.4.3	Auger Electron Spectroscopy (AES)	31
2.5	Manipulating the Growth	34
2.5.1	Manipulation via Variation of Temperature and Deposition Rate	34
2.5.2	Application of Surfactants	38
	References	41
<b>3</b>	<b>Structure of Ultrathin Films</b>	45
3.1	Structural Properties of Epitaxial Films	45
3.2	Thin-Film Characterization by Low-Energy Electron Diffraction	51
	References	59
<b>4</b>	<b>Magnetism of Ultrathin Metal Films</b>	61
4.1	Itinerant-Electron Magnetism	61
4.1.1	Local-Spin-Density Approximation	62
4.1.2	Stoner Model	64
4.1.3	Discussion	65
4.1.4	Itinerant Antiferromagnetism – Spin Density Waves in Bcc Cr	70
4.2	Magnetism of Ultrathin Films	72

X      Contents

4.2.1	Dimensionality Effects .....	73
4.2.2	Magnetic Moments at Surfaces and Interfaces .....	75
4.2.3	Magnetic Anisotropy in Ultrathin Films .....	81
4.3	Techniques for Magnetic Measurements on Ultrathin Films ..	86
4.3.1	Surface Magneto-optic Kerr Effect .....	86
4.3.2	X-Ray Magnetic Dichroism .....	92
4.3.3	Ferromagnetic Resonance (FMR) .....	107
	References .....	120
<b>5</b>	<b>Epitaxy-Stabilized Structures .....</b>	<b>125</b>
5.1	Theoretical Search for Metastable Structures .....	125
5.1.1	Vanadium .....	130
5.1.2	Chromium .....	131
5.1.3	Manganese .....	132
5.1.4	Iron .....	135
5.1.5	Cobalt .....	137
5.1.6	Nickel .....	141
5.2	Epitaxy-Stabilized Ultrathin Magnetic Films .....	142
5.2.1	Ultrathin V Films .....	142
5.2.2	Ultrathin Cr Films .....	143
5.2.3	Ultrathin Mn Films .....	145
5.2.4	Ultrathin Fe Films .....	159
5.2.5	Ultrathin Co Films .....	169
5.2.6	Ultrathin Bcc Ni Films .....	188
5.3	Epitaxially Stabilized Ultrathin Alloy Films .....	191
5.3.1	Theory of Epitaxy-Assisted Alloying .....	191
5.3.2	Epitaxial Alloy Thin Films .....	194
	References .....	201
<b>6</b>	<b>Correlation Between Magnetism, Structure and Growth for Ultrathin Fe Films on Cu(100) .....</b>	<b>209</b>
6.1	Introduction .....	209
6.2	Ultrathin Fe Films on Cu(100) .....	213
6.2.1	Early Work on Iron Films on Cu(100) .....	213
6.2.2	Magnetic Properties of Fe Films on Cu(100) .....	216
6.2.3	Growth of Fe Films on Cu(100) .....	220
6.2.4	Structure of Fe Films on Cu(100) <sup>1</sup> .....	226
6.2.5	Conclusions and Comparison with Other Studies .....	240
6.2.6	Correlation Between Magnetism, Structure and Growth .....	245
6.3	Topics Related to Ultrathin Fe/Cu(100) Films .....	249
6.3.1	Magnetic Order in Fe/Cu(100) Films and Its Origin ..	249
6.3.2	Structural and Magnetic Properties of Fe/Cu(100) Films Prepared at Low Temperature ..	256
6.3.3	Structural Instability of Ultrathin Fe/Cu(100) Films ..	261

6.3.4	Structure and Magnetism of Pulsed-Laser-Deposited Ultrathin Fe Films on Cu(100) . . . . .	264
6.3.5	Fe Ultrathin Films on Various Substrates with a Lattice Constant Close to That of Cu(100) . . . . .	268
	References . . . . .	275
<b>7</b>	<b>Manganese Films on Cu(100) and Ni(100) . . . . .</b>	<b>279</b>
7.1	Introduction . . . . .	279
7.2	Growth and Structure of Mn on Cu(100) and Ni(100) Below 270 K . . . . .	285
7.2.1	Growth of Ultrathin Mn Films on Cu(100) Below 270 K . . . . .	285
7.2.2	LEED Structure Determination of the $c(8 \times 2)$ Phase on Cu(100) . . . . .	287
7.2.3	Growth and Structure of Mn on Ni(100) Below 270 K . . . . .	291
7.2.4	Comparison of Mn Films Grown Below 270 K on Cu(100) and Ni(100) . . . . .	294
7.3	Growth and Structure of Mn on Cu(100) and Ni(100) Above 270 K . . . . .	297
7.3.1	Growth and Structure of Mn on Cu(100) above 270 K . . . . .	297
7.3.2	Structure Determination of the Cu(100) $c(2 \times 2)$ -Mn Phase . . . . .	299
7.3.3	Structural Transitions upon Annealing for Ultrathin Mn/Cu(100) Films . . . . .	304
7.3.4	Growth and Structure of Mn on Ni(100) Above 270 K . . . . .	307
7.3.5	Structure Determination of the Ni(100)- $c(2 \times 2)$ 0.5 ML Mn Phase . . . . .	309
7.3.6	Structure Determination of the Ni(100)- $c(2 \times 2)$ 4 ML Mn Phase . . . . .	310
7.3.7	Comparison with Other Systems . . . . .	319
7.4	Morphology of the Cu(100)- and Ni(100)- $c(2 \times 2)$ -Mn Surface Alloys . . . . .	321
7.5	The Role of Magnetic Energy in Stabilizing the Cu(100)- $c(2 \times 2)$ -Mn Surface Alloy . . . . .	329
7.6	Atomic Mechanism for the Formation of the Cu(100)- $c(2 \times 2)$ -Mn Surface Alloy . . . . .	334
7.6.1	STM Observations . . . . .	334
7.6.2	Scenario for Surface Alloy Formation . . . . .	344
7.6.3	Atomic Mechanisms for Surface Alloy Formation . . . . .	345
7.7	Electronic and Magnetic Properties of $c(2 \times 2)$ MnCu and MnNi Surface Alloys . . . . .	356
	References . . . . .	362

XII      Contents

<b>8    Summary and Outlook.....</b>	367
References .....	370
<b>Index .....</b>	371