

Contents

1. Introduction	1
2. Principles of Holography	2
2.1 In-Line Holography	3
2.2 Off-Axis Holography	6
2.3 Holography Using Two Different Kinds of Waves	8
3. Electron Optics	10
3.1 Electron Microscopy	10
3.1.1 Ray Diagram	10
3.1.2 Electron Guns	10
3.1.3 Electron Lenses	12
3.2 Interference Electron Microscope	13
3.3 Coherence Properties of Electron Beams	15
3.3.1 Temporal Coherence	16
3.3.2 Spatial Coherence	17
4. Historical Development of Electron Holography	20
4.1 In-Line Holography	21
4.2 Off-Axis Holography	25
5. Electron Holography	29
5.1 Electron-Hologram Formation	29
5.1.1 Ray Diagram	29
5.1.2 Experimental Apparatus	31
a) Electron Gun and Illumination System	31
b) Electron Interferometer	32
c) Recording System	33
5.2 Image Reconstruction	34
5.2.1 Interference Microscopy	34
5.2.2 Phase-Amplified Interference Microscopy	36
a) Optical Method	36
b) Numerical Method	39
c) Phase-Shifting Method in Optical Reconstruction	39
d) Phase-Shifting Method in Electron Microscopy	40
5.2.3 Three- Dimensional Imaging Reconstruction	41
5.2.4 Real-Time Observations	42
5.2.5 Image Restoration by Aberration Compensation	44
5.2.6 Micro-Area Electron Diffraction	47

6. Aharonov-Bohm Effect:	
The Principle Behind the Interaction of Electrons with Electromagnetic Fields	50
6.1 What is the Aharonov-Bohm Effect	51
6.2 Unusual Features of the Aharonov-Bohm Effect:	
Modified Double-Slit Experiments	53
6.3 The History of Vector Potentials	55
6.4 Fiber-Bundle Description of the Aharonov-Bohm Effect	56
6.5 Early Experiments and Controversy	60
6.5.1 Early Experiments	60
6.5.2 Nonexistence of the Aharonov-Bohm Effect	61
a) Non-Stokesian Vector Potential	61
b) Hydrodynamical Formulation	62
c) Doubts About the Validity of Early Experiments	63
6.5.3 Dispute About the Nonexistence of the Aharonov Bohm Effect	63
a) Non-Stokesian Vector Potentials	63
b) Hydrodynamical Formulation	64
c) Discussions on the Validity of Experiments	65
6.6 Experiments Confirming the Aharonov-Bohm Effect	66
6.6.1 An Experiment Using Transparent Toroidal Magnets	66
a) Sample Preparation	66
b) Experimental Results	68
c) Discussions of the Validity of the Experiment	69
6.6.2 An Experiment Using Toroidal Magnets Covered with a Superconducting Film	70
a) Sample Preparation	70
b) Experimental Results	72
7. Electron-Holographic Interferometry	78
7.1 Thickness Measurements	78
7.1.1 Principle of the Measurement	78
7.1.2 Examples of Thickness Measurement	79
7.1.3 Other Applications	82
7.2 Surface Topography	83
7.3 Electric Field Distribution	84
7.4 Domain Structures in Ferromagnetic Thin Films	85
7.4.1 Measurement Principles	85
7.4.2 Magnetic Domain Walls in Thin Films	87
7.5 Domain Structures in Fine Ferromagnetic Particles	90
7.6 Magnetic Devices	93
7.7 Domain Structures in Three-Dimensional Particles	96
7.8 Three-Dimensional Image	99
7.8.1 Electric Potentials	99
7.8.2 Magnetic Fields	100
7.9 Dynamic Observation of Domain Structures	102

7.10 Static Observation of Fluxons in the Profile Mode	103
7.10.1 Quantized Flux (Fluxons)	103
7.10.2 Experimental Method	104
7.10.3 Experimental Results	105
7.11 Dynamic Observation of Fluxons in the Profile Mode	108
7.11.1 Thermally Excited Fluxons	108
7.11.2 Current-Driven Fluxons	110
a) Experimental Method	111
b) Experimental Results	116
7.12 Observation of Fluxons in the Transmission Mode	117
7.12.1 Experimental Methods	117
7.12.2 Experimental Results	118
a) Behavior of Fluxons in Nb Thin Films	118
b) Estimation of Pinning Forces of Defects	121
c) Intermittent Rivers of Fluxons	122
d) Matching Effect	124
e) High- T_c Superconductors	130
8. High-Resolution Microscopy	133
8.1 Phase Contrast Due to Aberration and Defocusing	133
8.2 Optical Correction of Spherical Aberration	138
8.2.1 In-Focus Electron Micrograph of a Crystalline Particle	138
8.2.2 Off-Axis Hologram of a Crystalline Particle	139
8.2.3 Image Reconstruction	141
8.2.4 Spherical Aberration Correction	141
8.3 Numerical Correction of Spherical Aberration	143
9. Conclusions	146
References	147
Subject Index	159