

Contents

Preface *xi*

Foreword *xiii*

1	Introduction	1
1.1	Big Data Era	1
1.2	History of Holographic Data Storage	4
1.3	Present Problems	9
1.3.1	Recording Medium	9
1.3.2	Multiplexing Diffraction Efficiency	10
1.3.3	Media Duplication	10
1.3.4	Pixel Matching	10
1.3.5	High-Speed Reading	11
	References	11
 2	 System of Collinear Holography	 17
2.1	Polarized Collinear Holography	17
2.1.1	Introduction	17
2.1.2	Magneto-Optical Holography and Principle of Polarization Separation and Reproduction	17
2.1.3	Basic Principle of Polarization Collinear Holography	19
2.1.4	Results of Experiments to Verify the Basic Principle of Polarization Collinear Holography	23
2.2	Principle of Collinear Holography	23
2.2.1	Introduction	23
2.2.2	Basic Technology of Holographic Optical Memory	25
2.2.2.1	Interference and Diffraction	25
2.2.2.2	Multiplexing Technology	26
2.2.3	Recording and Playback Method of Collinear Holography and Its Proof of Principle	29
2.2.4	Practical Collinear Method of Optical Memory	32
2.2.4.1	Basic Concept	32
2.2.4.2	Basic Collinear Optical System	34

2.3	Collinear Recording and Reproduction Characteristic Evaluation Device: S-VRD	37
2.4	B-VRD	40
2.5	HVD-ES1	47
2.5.1	System Overview and Background of Development	47
2.5.2	Overall System Configuration	48
2.5.3	Main Unit	49
2.5.3.1	Hardware and Parameters	49
2.5.3.2	System Controller Section	49
2.5.4	Recording Playback Condition and Corresponding Media	53
2.5.5	Specifications	53
2.6	SHOT-2000 (Standard Holographic Optical Tester for Collinear System)	54
2.6.1	History of SHOT-2000 Development	54
2.6.2	SHOT-2000 System Outline	56
2.6.2.1	Device Appearance	56
2.6.2.2	Actuality of Disc Evaluation	56
2.6.2.3	Block Diagram	56
2.6.3	Optical System (Light Source, SLM, Actuator, Camera, etc.)	58
2.6.3.1	Green Laser	58
2.6.3.2	SLM (DMD)	58
2.6.3.3	Objective Lens Unit	59
2.6.3.4	Structure of HVD	59
2.6.3.5	CMOS Camera	60
2.6.3.6	Red Laser for Servo	60
2.6.4	Control System	61
2.6.5	Control Software (Recording, Reconstruction, Sequence Control, and so on)	61
2.6.5.1	Parameter Setting Screen	61
2.6.5.2	Evaluation Result Display Screen	61
2.6.5.3	Evaluation Items	63
2.6.6	Current Research and Development Using SHOT-2000	63
	Glossary	64
	References	64
3	Theories of Collinear Holography	67
3.1	Analysis of a Collinear Holographic Storage System: Introduction of Pixel Spread Function	67
3.2	Theoretical Treatment of the Collinear System and Formulate Numerical Evaluation Technique Based on the Scalar Diffraction Theory	73
3.2.1	Principle of Optical Autocorrelation Method	73
3.2.2	Simulation Scheme for Collinear System	75
3.2.2.1	Formulization of VIE	75
3.2.2.2	Recording Process	76
3.2.3	Numerical Evaluation	76

3.3	Orthogonal Reference Patterns Multiplexing for Collinear Holographic Data Storage	78
3.3.1	Principle of the ORPM Method	78
3.3.1.1	Theoretical Formulation for the RPM Method	79
3.3.1.2	Orthogonal Condition	81
3.3.1.3	Parallel Optical Image Superimposition	82
3.3.1.4	Orthogonal Radial-Line RPs	83
3.3.2	Crosstalk Analysis for ORPM	83
3.3.3	Orthogonal Reference Patterns Modulated Shifting Multiplexing	86
3.3.4	Experimental Results	89
3.4	Simulation of Interference Fringes Formed by Collinear Method	91
	References	97
4	Key Devices and Components	99
4.1	Lasers	99
4.1.1	Introduction	99
4.1.2	Solid Lasers for Collinear Technology	101
4.1.3	Laser Diode for HVD-ROM	104
4.1.4	Conclusions	106
4.2	DMD	106
4.3	CMOS	112
4.4	Servo Actuator	115
	References	120
5	Materials	123
5.1	Holographic Media for Commercial Uses	123
5.1.1	Introduction	123
5.1.2	Media Developed by InPhase and Aprilis	123
5.1.2.1	HDS Recording System	123
5.1.2.2	InPhase Media	124
5.1.2.3	Aprilis Media	127
5.1.3	Conclusion	128
5.2	Holographic Photopolymer Materials	129
5.2.1	Introduction	129
5.2.2	Photopolymerization and Grating Formation Processes	129
5.2.2.1	Photochemical Reactions	129
5.2.2.2	Holographic Grating Formation in a Binder-Based Photopolymer	131
5.2.2.3	Holographic Grating Formation in an NPC	132
5.2.3	Holographic Characterization Methods	132
5.2.4	Holographic Photopolymer Materials and Their Improvement for a High-Spatial-Resolution Recording	134
5.2.5	Conclusion	137
5.3	PQ/PMMA	138
5.3.1	Introduction	138
5.3.2	Material Preparation	139

5.3.3	Photochemical Reaction	140
5.3.4	Results and Discussions	141
5.3.4.1	Fourier Transform Infrared Spectroscopic Measurements	141
5.3.4.2	Ultraviolet-Visible Spectroscopic Measurements	142
5.3.4.3	Photoinduced Birefringence	142
5.3.4.4	Orthogonal Linearly Polarized Holography	143
5.3.5	Applications	146
	References	147
6	Data Format	155
6.1	3:16 Modulation	155
6.2	Sync Format	157
6.3	Reference Pattern	160
6.3.1	Dependence on the Reference Patterns	161
6.3.2	Dependence on the Width of the Reference Pattern	161
6.3.3	Adjustment Light Energy Ratio	164
6.4	Phase Modulation	165
6.4.1	Introduction	165
6.4.2	Fundamental Principle of Optical Phase-Locked Collinear System	167
6.4.2.1	Fundamental Principles and Experimental Results	167
6.4.2.2	Optical Recording and Reproducing System for Optical Phase Locking	169
6.4.2.3	Page Data Structure of Optical Phase-Locked System	169
6.4.2.4	Phase and Multipage Data Recording and Playback Process	172
6.4.3	Phase Locked Multi Phase Recording with Optical Phase Locking	175
6.4.3.1	Fundamental Experiment of Four-Phase Gradation Recording	175
6.4.3.2	Factor Analysis of Phase Error	177
6.4.4	Phase Multi Level Gray Scale Recording and Reproduction Characteristics of Optical Phase-Locked System	178
6.4.5	Fundamental Principles of Phase Encoding Multiplexed Recording	180
6.4.6	Summary	183
6.5	Low-Density Parity-Check Code	184
6.6	Disc Format	186
6.6.1	Playback Sequence	186
6.6.2	On-the-Fly Recording/Playback Experiment	188
	References	192
7	Characteristics of Write and Read	195
7.1	Introduction	195
7.2	Shift Selectivity	196
7.2.1	Evaluation of Playback Signal Strength with Respect to Movement of Playback Position	196
7.2.2	Demonstration of Collinear Shift Multiplex Recording and Playback Principle	198

7.3	Parameters	200
7.3.1	$M/\#$	200
7.3.2	SNR	200
7.4	Symbol Error	202
7.4.1	Burst Error Determination and Image Observation of Error Part	202
7.4.2	Estimation of Noise Generation Using Numerical Simulations	206
7.5	Numerical Analysis of Collinear Shift Selectivity	208
7.6	Summary	210
	References	210

8 System Margin of a Collinear Holographic Data Storage System 213

8.1	Defocus Margin	213
8.2	Detrack Margin	214
8.3	Image Plane Margins	215
8.4	Tilt Margin	217
8.4.1	Absolute Value Tilt Margin	217
8.4.2	Relative Value Tilt Margin	218
8.5	Wavelength Margin	219
8.5.1	Wavelength Shift Margin	220
8.5.2	Wavelength Spectrum Margin	222
8.6	Temperature Compensation for Collinear Holographic Data Storage	225
8.6.1	Introduction	225
8.6.2	Thermal Effects of the CHDSS	225
8.6.3	Temperature Compensation Condition for the CHDSS	228
8.6.4	Summary	230
8.7	Noise Margin	230
8.7.1	Noise Margin Improvement in Binary Modulation HDS	231
8.7.2	Noise Margin Improvement in Multilevel Modulation HDS	232
8.7.2.1	Convolutional Neural Network Decoding	232
8.7.2.2	Compressed Sensing Decoding	233
8.7.3	Summary	234
	References	235

9 Applications 237

9.1	High-Speed Optical Correlation System Based on Collinear Holography	237
9.1.1	Introduction	237
9.1.2	Optical Correlator Based on Collinear Holography	238
9.1.2.1	Basic Concept of Optical Correlator	238
9.1.2.2	Optical Setup	238
9.1.2.3	Correlation Speed	243
9.1.3	Applications of the Optical Correlator Based on Collinear Holography	243

9.1.3.1	Basic Configuration	243
9.1.3.2	Face Recognition Application	244
9.1.3.3	Image Retrieval Function	245
9.1.3.4	Sketch-Based Image Retrieval Application	247
9.2	3D Holographic Printer	249
9.2.1	Introduction	249
9.2.2	Principle of Exposure Formation of Lippmann Hologram by Collinear Method	250
9.2.3	Hologram Recording/Reproduction Principle of Full Parallax 3D Image	252
9.2.4	Holographic 3D Printer System: CDP-1	253
9.2.5	Exposure Printing of 3D Images Using CDP-1	255
9.2.6	Summary	257
9.3	Encryption	258
	References	259

Index	263
--------------	-----