

TABLE OF CONTENTS

DEDICATION.....	v
FOREWORD.....	vii
PREFACE.....	ix
AUTHOR'S PREFACE I.....	xi
AUTHOR'S PREFACE II.....	xii
Chapter 1 INTRODUCTION AND HISTORY.....	1
References.....	5
Chapter 2 COMPOSITION, STRUCTURE AND PROPERTIES OF INORGANIC AND ORGANIC GLASSES.....	7
2.1 Glass-Forming Inorganic Materials.....	7
2.1.1 Crystallite Theory.....	8
2.1.2 Random Network Theory.....	9
2.1.3 Phase Separation, Devitrification.....	10
2.1.4 Glass Forming Organic Materials.....	11
2.1.5 Crystalline and Amorphous Behaviour of Polymers.....	12
2.2 Thermal Behaviour of Inorganic and Organic Glasses.....	12
2.3 Mechanical Properties of Inorganic Glasses.....	14
2.4 Chemical Properties of Inorganic Glasses.....	15
2.5 Electrical Properties.....	17
2.6 Optical Properties.....	19
2.7 Materials Transparent in Ultraviolet and Infrared.....	21
2.8 Photochromic Glasses.....	24
2.9 Glass Ceramics.....	27
2.10 Glass Materials for Advanced Technology and for Selected High Precision Applications.....	31
2.10.1 Laser Glasses.....	32
2.10.2 Glass Ceramics and Ultra Low Expansion Glass Optics...	32
2.10.2.1 Laser Gyroscopes.....	33
2.10.2.2 Space Telescopes.....	33
2.10.2.3 Large Ground-Based Optical Telescopes.....	34
2.10.3 Glasses for Photonics.....	34
2.10.4 Glasses for the Building Industry.....	35
2.10.4.1 Thermal Insulation.....	35
2.10.4.2 Noise Reduction.....	35
2.10.4.3 Safety Improvement.....	36
2.10.4.4 Fire Prevention.....	36

2.10.4.5	Solar Protection.....	36
	References.....	36
Chapter 3	NATURE OF A SURFACE.....	40
3.1	Characterization of a Surface.....	40
3.1.1	Structure of a Surface.....	41
3.1.2	Chemical Composition of a Surface.....	42
3.1.3	Energy of a Surface.....	44
3.1.4	Morphology of a Surface.....	45
3.1.5	Interactions Solid/Gas and Solid/Solid.....	47
3.2	Production of Glass Surfaces.....	50
3.2.1	Drawing and Casting.....	50
3.2.2	Pressing and Moulding.....	51
3.2.3	Grinding and Polishing.....	52
	References.....	57
Chapter 4	CLEANING OF SUBSTRATE SURFACES.....	60
4.1	Cleaning Procedures.....	61
4.1.1	Cleaning with Solvents.....	61
4.1.1.1	Rubbing and Immersion Cleaning.....	62
4.1.1.2	Vapour Degreasing.....	63
4.1.1.3	Ultrasonic Cleaning.....	63
4.1.1.4	Spray Cleaning.....	64
4.1.2	Cleaning by Heating and Irradiation.....	64
4.1.3	Cleaning by Stripping Lacquer Coatings.....	65
4.1.4	Cleaning in an Electrical Discharge.....	66
4.1.5	Cleaning Cycles.....	67
4.1.6	Cleaning of Organic Glass.....	68
4.2	Methods for Control of Surface Cleanliness.....	69
4.3	Maintenance of Clean Surfaces.....	70
	References.....	71
Chapter 5	GLASS AND THIN FILMS.....	73
5.1	Correlation between Glass and Thin Films.....	73
5.2	Adhesion between Substrate and Film.....	75
5.2.1	Methods of Adhesion Measurement.....	77
5.2.1.1	Mechanical Methods.....	78
5.2.1.2	Non-Mechanical Methods.....	80

5.2.2	Causes of Adhesion.....	83
5.2.2.1	Interface Layers.....	83
5.2.2.2	Types of Bonding.....	84
5.2.3	Parameter Influencing Adhesion.....	86
5.2.3.1	Coating and Substrate Materials.....	87
5.2.3.2	Substrate Preparation.....	87
5.2.3.3	Influence of the Coating Method.....	88
5.2.3.4	Aging.....	88
5.2.4	Practical Aspects of Adhesion Measurement.....	88
5.2.4.1	Scotch Tape Test.....	89
5.2.4.2	Direct Pull-Off Method.....	90
5.2.4.3	Scratch Method.....	92
5.2.5	Final Comments to Adhesion.....	98
	References	98

Chapter 6	FILM FORMATION METHODS.....	103
6.1.	Subtractive Methods.....	103
6.1.1	Chemical Processes.....	103
6.1.1.1	Surface Leaching.....	103
6.1.2	Physical Processes.....	104
6.1.2.1	High Energy Particle Bombardment.....	104
6.2	Additive Methods.....	105
6.2.1	Chemical Film Formation Processes.....	105
6.2.1.1	Deposition of Metal Films from Solutions.....	105
6.2.1.2	Deposition of Oxide Films from Solutions.....	107
6.2.1.2.1	Immersion or Dip-Coating.....	107
6.2.1.2.1.1	Formation, Structure, Optical and Mechanical Properties.	107
6.2.1.2.1.2	Coating Procedure.....	121
6.2.1.2.1.3	Trends in Sol-Gel Development and Processing.....	126
6.2.1.2.2	Spin Coating.....	127
6.2.1.3	Deposition of Organic Films from Solutions.....	128
6.2.1.4	Chemical Vapour Deposition at Low Temperatures.....	130
6.2.1.4.1	Atmospheric-Pressure and Low-Pressure CVD.....	134
6.2.1.4.1.1	Spray Coating.....	134
6.2.1.4.1.2	Atmospheric-Pressure CVD.....	139
6.2.1.4.1.2.1	Compound Films.....	141
6.2.1.4.1.2.2	Metal Films.....	144
6.2.1.4.1.3	Low-Pressure CVD.....	149
6.2.1.4.2	Plasma-Activated and Photon-Activated CVD.....	150
6.2.1.4.2.1	Plasma-Activated CVD.....	150
6.2.1.4.2.2	Photon-Activated CVD.....	155
6.2.1.5	Physical Vapour Deposition.....	156

6.2.1.5.1	Vacuum Technology.....	157
6.2.1.5.1.1	Vacuum Pumps.....	161
6.2.1.5.1.1.1	Mechanical Displacement Pumps.....	161
6.2.1.5.1.1.2	Diffusion Pumps.....	165
6.2.1.5.1.1.3	Molecular Pumps.....	168
6.2.1.5.1.1.4	Cryo Pumps.....	172
6.2.1.5.1.2	High-Vacuum Process Systems.....	174
6.2.1.5.2	Film Deposition by Evaporation and Condensation in High Vacuum.....	185
6.2.1.5.2.1	Evaporation.....	186
6.2.1.5.2.2	Energy, Velocity and Directional Distribution of the Vapour Atoms and Thickness Uniformity of the Films....	190
6.2.1.5.2.3	Efficiency of Energy and Mass.....	205
6.2.1.5.2.4	Evaporation Techniques.....	207
6.2.1.5.2.5	Transit of the Vapourized Species Through the Reduced Atmosphere.....	214
6.2.1.5.2.6	Condensation and Film Formation.....	215
6.2.1.5.2.7	Evaporation Materials.....	219
6.2.1.5.2.8	Evaporation Plants.....	223
6.2.1.5.3	Film Deposition by Cathode Sputtering.....	230
6.2.1.5.3.1	General Considerations.....	230
6.2.1.5.3.2	Sputtering Threshold and Sputtering Yield.....	235
6.2.1.5.3.3	Ejection of other Particles and Emission of Radiation....	239
6.2.1.5.3.4	Ion Implantation.....	240
6.2.1.5.3.5	Alterations in Surface Films, Diffusion and Dissociation.	241
6.2.1.5.3.6	Sputtering Rate.....	241
6.2.1.5.3.7	Particle Velocity and Energy.....	243
6.2.1.5.3.8	Angular Distribution.....	243
6.2.1.5.3.9	Composition of the Sputtered Material.....	244
6.2.1.5.3.10	The Gas Discharge.....	244
6.2.1.5.3.11	State of the Art in Industrial Magnetron Sputtering.....	256
6.2.1.5.3.12	Ion Beam Sputtering.....	258
6.2.1.5.3.13	Thickness Uniformity and Mass Efficiency in Sputtering	259
6.2.1.5.3.14	Sputtering Materials.....	262
6.2.1.5.3.15	Sputtering Plants.....	265
6.2.1.5.3.16	Comparison Evaporation and Sputtering.....	265
6.2.1.5.4	Film Deposition by Ion Plating.....	267
6.2.1.5.4.1	Characteristics of Ion Plating.....	268
6.2.1.5.4.2	Advantages of Ion Plating.....	274
6.2.1.5.4.3	Applications of Ion Plating.....	277
6.2.1.5.5	Reactive Deposition Processes.....	280
6.2.1.5.5.1	General Considerations.....	280
6.2.1.5.5.2	Reactive Evaporation.....	281
6.2.1.5.5.3	Activated Reactive Evaporation.....	286

6.2.1.5.5.4	Reactive Sputtering.....	290
6.2.1.5.5.5	Reactive Ion Plating.....	293
6.2.1.5.6	Plasma Polymerization.....	294
	References.....	300
Chapter 7	FILM THICKNESS.....	318
7.1	General Considerations.....	318
7.2	Methods Applicable to all Types of Films.....	319
7.2.1	Interference Methods.....	319
7.2.2	Stylus Methods.....	323
7.3	Methods Applicable to PVD Films.....	324
7.3.1	Optical Reflectance and Transmittance Measurements.....	324
7.3.2	Oscillating Quartz-Crystal Microbalance.....	328
7.3.3	Vapour-Density Measurement by Mass Spectrometry.....	335
7.4	Trends in Monitoring Technology.....	337
	References.....	339
Chapter 8	PROPERTIES OF THIN FILMS.....	343
8.1	Structure.....	343
8.2	Microstructure.....	354
8.3	Chemical Composition.....	364
8.3.1	Surface Analysis.....	364
8.3.2	Depth Profiling.....	367
8.4	Mechanical Properties.....	373
8.4.1	Stress.....	374
8.4.2	Hardness and Abrasion.....	385
8.4.3	Density.....	389
8.5	Chemical and Environmental Stability.....	390
8.6	Optical Properties of Thin Films.....	394
8.7	Relation between Density, Stress and Optical Film Properties.....	413
8.8	Electro-Optical Materials and their Properties.....	414
	References.....	417
Chapter 9	APPLICATION OF COATINGS ON GLASS.....	429
9.1	General Considerations.....	429
9.2	Calculation of Optical Film Systems.....	433
9.3	Antireflective Coatings.....	437

9.3.1	Single-Layer Antireflection Coatings.....	437
9.3.2	Double-Layer Antireflection Coatings.....	440
9.3.3	Multilayer Antireflection Coatings.....	441
9.3.4	Antireflection Coatings at Oblique Incidence.....	444
9.3.5	Inhomogeneous Antireflection Coatings.....	444
9.3.6	Applications of Antireflection Coatings.....	445
9.4	Rear Surface Mirrors, Surface Mirrors and Beam Splitter Mirrors.....	446
9.4.1	Rear Surface ACE Mirrors.....	447
9.4.2	Metal Film Surface Mirrors.....	447
9.4.3	Beam Splitter Mirrors.....	452
9.4.4	Neutral Density Filters.....	458
9.4.5	Dielectric Mirrors.....	458
9.4.6	Cold Light Mirrors and Heat Mirrors.....	460
9.4.7	Laser Coatings.....	463
9.4.8	Artificial Jewels.....	466
9.5	Separation of Light by Filters.....	467
9.5.1	Low- and High-Pass Edge Filters.....	467
9.5.2	Band Pass Interference Filters.....	472
9.5.2.1	Narrow-Band Filters.....	472
9.5.2.2	Broad Band Filters.....	476
9.6	Absorptive Coatings.....	477
9.6.1	Eye Protection Coatings.....	477
9.6.2	Photo Masks.....	478
9.6.3	Scales, Reticles, Apertures.....	480
9.6.4	Phase Plates.....	480
9.7	Transparent Conductive Coatings.....	482
9.8	Energy-Related Coatings.....	484
9.9	Solderable Coatings.....	486
9.10	Integrated Optics.....	486
9.10.1	Integrated Optics Components.....	487
9.10.2	Present Status and Trend.....	492
9.11	Scientific Applications.....	496
	References.....	499