

# Table of Contents

<b>1 Overview – Optical Glass: An Engineered Material</b>	
<i>Alexander J. Marker III, Norbert Neuroth</i> . . . . .	1
1.1 Glass: An Important Material for Optics . . . . .	1
1.2 Essential Properties . . . . .	2
1.3 History of Development . . . . .	3
1.4 Selected Applications . . . . .	4
1.5 Progress in Manufacturing Technology . . . . .	6
1.6 Today's Interests . . . . .	7
References . . . . .	11
<b>2 Optical Properties</b>	
<i>Marc K. Th. Clement, Joseph S. Hayden, Yuiko T. Hayden,</i> <i>Hans-Jürgen Hoffmann, Frank-Thomas Lentz, Norbert Neuroth</i> . . . . .	19
2.1 Refractive Index and Dispersion <i>Frank-Thomas Lentz</i> . . . . .	19
2.1.1 Introduction . . . . .	19
2.1.2 Law of Refraction . . . . .	19
2.1.3 Dispersion and the Various Dispersion Formulae . . . . .	20
2.1.4 Measurement and Limitations of the Accuracy of Refractive Index Data . . . . .	27
2.1.5 Definition of the Characteristic Properties of Optical Glasses . . . . .	29
2.2 The Chemical Composition of Optical Glasses and Its Influence on the Optical Properties <i>Marc K. Th. Clement</i> . . . . .	59
2.2.1 General Remarks . . . . .	59
2.2.2 Glass Types . . . . .	66
2.2.3 Reduction of the Density . . . . .	72
2.2.4 Development of Optical Glasses . . . . .	73
2.3 Transmission and Reflection <i>Norbert Neuroth</i> . . . . .	82
2.3.1 General Relations . . . . .	82
2.3.2 Sources of Optical Loss in Glass . . . . .	85
2.3.3 Examples of Transmission Spectra . . . . .	90
2.3.4 Influence of Temperature . . . . .	93
2.3.5 Influence of Radiation on the Transmission . . . . .	94

2.4	Differential Changes of the Refractive Index	
	<i>Hans-Jürgen Hoffmann</i> . . . . .	96
2.4.1	General Remarks . . . . .	96
2.4.2	The Refractive Index of Air and Its Variations . . . . .	97
2.4.3	Thermal Treatment of Glasses and the Refractive Index . . . . .	99
2.4.4	The Thermo-Optical Coefficient . . . . .	105
2.4.5	Photoelastic Properties of Glasses . . . . .	108
2.4.6	The Electro-Optic Effect in Glasses (Kerr-Effect) . . . . .	114
2.4.7	Magneto-Optic Effects in Glasses . . . . .	115
2.4.8	Further Possibilities . . . . .	120
2.5	Acousto-Optical Properties of Glasses <i>Hans-Jürgen Hoffmann</i> . . . . .	123
2.5.1	Acousto-Optical Effects and Applications . . . . .	123
2.5.2	Characterization of Glasses . . . . .	125
2.6	Nonlinear Optical Properties <i>Yuiko T. Hayden,</i> <i>Joseph S. Hayden</i> . . . . .	130
2.6.1	Homogeneous Glasses . . . . .	131
2.6.2	Heterogeneous Glasses – Semiconductor-Doped Glasses . . . . .	134
2.6.3	Heterogeneous Glasses – Metallic Particle Doped Glasses . . . . .	137
2.6.4	Heterogeneous Glasses – Other Systems . . . . .	137
2.7	Resistance to Laser Radiation <i>Joseph S. Hayden</i> . . . . .	139
2.7.1	Bulk Damage Resistance to Laser Radiation . . . . .	139
2.7.2	Surface Damage Resistance to Laser Irradiation . . . . .	142
2.7.3	Multiphoton Darkening of Optical Glass . . . . .	143
	References . . . . .	144
<b>3</b>	<b>Optical Quality</b>	
	<i>Frank-Thomas Lentz, Norbert Neuroth</i> . . . . .	167
3.1	Tolerances of the Refractive Index and the Abbe Number . . . . .	167
3.1.1	Uniformity . . . . .	167
3.2	Colouration, Solarization and Fluorescence . . . . .	172
	References . . . . .	177
<b>4</b>	<b>Mechanical Properties</b>	
	<i>Kurt Nattermann, Norbert Neuroth, Robert J. Scheller</i> . . . . .	181
4.1	Density . . . . .	181
4.2	Elastic Modulus, Poisson's Ratio, Specific Thermal Tension . . . . .	181
4.3	Microhardness . . . . .	185
4.4	Strength of Glasses . . . . .	190
4.4.1	Introduction . . . . .	190
4.4.2	Brittle Fracture of Glass . . . . .	190
4.4.3	Fractography . . . . .	192
4.4.4	Sub-Critical Crack Growth . . . . .	193
4.4.5	Fracture Probability . . . . .	194
4.4.6	Testing of Glasses . . . . .	196
4.4.7	Three-Point Bending . . . . .	196
4.4.8	Ring-on-Ring Test . . . . .	197

4.5	Strengthening of Glass . . . . .	198
4.5.1	Thermal Strengthening . . . . .	199
4.5.2	Chemical Strengthening . . . . .	200
	References . . . . .	200
<b>5</b>	<b>Thermal Properties of Glass</b>	
	<i>Ulrich Fotheringham</i> . . . . .	203
5.1	Heat Capacity . . . . .	203
5.2	Thermal Conductivity . . . . .	210
5.2.1	The Phononic Contribution to the Thermal Conductivity . . . . .	211
5.2.2	The Radiative Heat Transfer in Opaque Glass . . . . .	213
5.2.3	The Radiative Heat Transfer in Transparent Glass . . . . .	214
5.3	Thermal Expansion . . . . .	221
5.4	Viscosity . . . . .	225
	References . . . . .	228
<b>6</b>	<b>Chemical Durability of Optical Glass: Testing Methods – Basic Information, Comparison of Methods Applied by Different Manufacturers and International Testing Standards</b>	
	<i>Wilfried Heimerl, Arnd Peters</i> . . . . .	231
6.1	Introduction . . . . .	231
6.2	General Chemical Reactions with Water (Neutral Aqueous Solutions) on the Glass Surface . . . . .	232
6.3	Processing and Chemical Reactions . . . . .	232
6.4	Cleaning and Its Possible Effects . . . . .	234
6.5	Testing Methods . . . . .	234
6.5.1	International Standard Procedures . . . . .	236
6.5.2	Comparison of Methods for Testing the Chemical Durability of Optical Glasses, Using Solid Polished Glass Plates as Samples . . . . .	240
6.5.3	Comparison of Methods for Testing the Chemical Durability of Optical Glasses Using Powdered Glass as Sample . . . . .	243
6.6	Discussion . . . . .	244
	References . . . . .	245
<b>7</b>	<b>Processing (Grinding and Polishing)</b>	
	<i>Knut Holger Fiedler</i> . . . . .	247
7.1	Introduction . . . . .	247
7.1.1	Grinding and Polishing . . . . .	247
7.1.2	Material Removal Rate . . . . .	248
7.1.3	Historical Background . . . . .	248
7.2	Glass Grinding . . . . .	249
7.2.1	Indentation and Scratching . . . . .	249
7.2.2	Loose Abrasive Grinding . . . . .	250
7.2.3	Fixed Abrasive Grinding . . . . .	251

7.3	Glass Polishing . . . . .	254
7.3.1	Full Lap Polishing Techniques . . . . .	254
7.3.2	Sub Aperture Polishing . . . . .	257
7.3.3	Influences of Chemistry in Glass Polishing . . . . .	258
7.4	Advanced Material Removal Techniques . . . . .	259
7.5	Conclusion and Future Work . . . . .	260
	References . . . . .	261

## 8 Selected Applications

	<i>Joseph S. Hayden, Ewald Hillmann, Hans-Jürgen Hoffmann, Uwe Kolberg, David Krashkevich, Monika J. Liepmann, Susan R. Loehr, Peter Naß, Norbert Neuroth, Burkhard Speit . . . . .</i>	265
8.1	Ophthalmic Glasses <i>David Krashkevich, Susan R. Loehr . . . . .</i>	265
8.1.1	History of Ophthalmic Lenses . . . . .	265
8.1.2	The Optics of Vision and Ophthalmic Lenses . . . . .	265
8.1.3	Properties of Ophthalmic Glasses . . . . .	269
8.1.4	Multifocal Ophthalmic Lenses . . . . .	270
8.1.5	Strengthening of Ophthalmic Lenses . . . . .	272
8.2	Photochromic Glasses <i>Hans-Jürgen Hoffmann . . . . .</i>	275
8.2.1	Basic Principles of Photochromic Effects . . . . .	275
8.2.2	Photochromic Oxidic Glasses Doped with Silver Halides . . . . .	276
8.2.3	Qualitative Description of the Darkening and the Regeneration Mechanisms of the Photochromic Glasses . . . . .	281
8.2.4	Photochemical Reaction Kinetics in Photochromic Glasses . . . . .	283
8.2.5	Generalisations and Consequences . . . . .	288
8.2.6	Conclusions . . . . .	289
8.3	Ultraviolet-Transmitting Glasses <i>Monika J. Liepmann, Norbert Neuroth . . . . .</i>	290
8.3.1	Intrinsic Absorption . . . . .	290
8.3.2	Effects of Impurities . . . . .	295
8.3.3	Commercial Glasses . . . . .	296
8.4	Infrared-Transmitting Glasses <i>Monika J. Liepmann, Norbert Neuroth . . . . .</i>	299
8.4.1	Sources of Absorption . . . . .	299
8.4.2	Oxide Glasses . . . . .	300
8.4.3	Halide Glasses . . . . .	303
8.4.4	Chalcogenide Glasses . . . . .	305
8.4.5	Commercial Glasses . . . . .	307
8.5	Laser Glasses <i>Joseph S. Hayden, Norbert Neuroth . . . . .</i>	310
8.5.1	Requirements for Laser Glass Materials . . . . .	310
8.5.2	Activating Ions . . . . .	314
8.5.3	Glass Development . . . . .	315
8.5.4	Process Development . . . . .	319
8.5.5	Commercial Neodymium Laser Glasses . . . . .	322
8.5.6	Functional Forms of Laser Glass . . . . .	323

8.5.7	Applications of Laser Glass and Future Development Trends . . . . .	324
8.6	Glasses for High Energy Particle Detectors <i>Susan R. Loehr, Peter Naß, Burkhard Speit</i> . . . . .	326
8.6.1	Introduction . . . . .	326
8.6.2	X-ray Sensitive Glasses . . . . .	327
8.6.3	Scintillating Glass Calorimeter . . . . .	329
8.6.4	Čerenkov Glass Counters . . . . .	331
8.6.5	Active Glasses for Scintillating Fibres . . . . .	333
8.6.6	Glass Capillaries Filled with Liquid Scintillator for High Resolution Detectors . . . . .	336
8.7	Special Glasses for Nuclear Technologies <i>Burkhard Speit</i> . . . . .	341
8.7.1	Radiation Shielding Glasses . . . . .	341
8.7.2	Radiation Resistant Optical Glasses . . . . .	344
8.7.3	Dosimeter Glasses . . . . .	347
8.7.4	Glasses for Nuclear Fusion . . . . .	350
8.8	Coloured Glasses <i>Uwe Kolberg</i> . . . . .	351
8.8.1	Introduction . . . . .	351
8.8.2	The Basics of Colour Generation in Glasses . . . . .	356
8.8.3	Trends in the Development of Coloured Glasses of Schott . . . . .	368
8.9	Glasses for Eye Protection <i>Ewald Hillmann, Norbert Neuroth</i> . . . . .	371
8.9.1	The Eye . . . . .	371
8.9.2	Protective Glasses . . . . .	371
	References . . . . .	381
	<b>List of Contributing Authors</b> . . . . .	401
	<b>Sources of Figures</b> . . . . .	402
	<b>Index</b> . . . . .	405