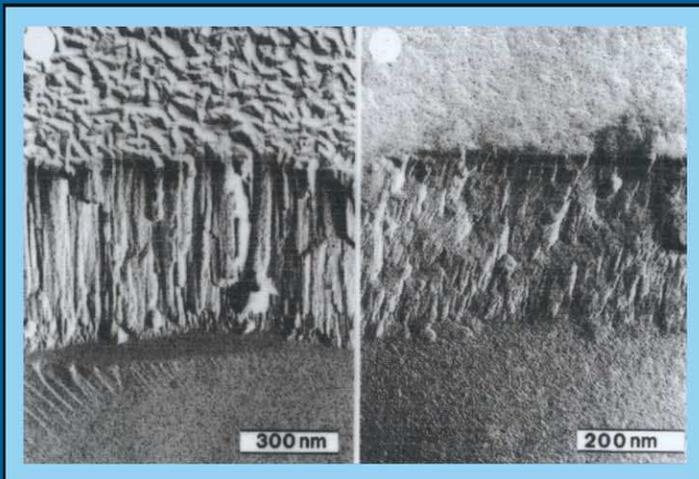


# *Coatings on Glass*

*Second, revised edition*

H.K. PULKER



ELSEVIER

# *Coatings on Glass*

Cover illustration:

AlN films

(left)

$E_{\text{kin}} = \text{low}$

$\rho = \text{low}$

$n_{550} = 1.98$

$\sigma_{\text{tens.}} = 0.3 \text{ GPa}$

(right)

$E_{\text{kin}} = \text{high}$

$\rho = \text{high}$

$n_{550} = 2.12$

$\sigma_{\text{comp.}} = -0.9 \text{ GPa}$

AlN polycrystalline

E. Rille, R. Zarwash and H.K. Pulker, Thin Solid Films 228 (1993) 215

Th. Müller and H.K. Pulker, Thin Solid Films 246 (1994) 42

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*Second, revised edition*

H.K. PULKER

*Basic Research Laboratory, Balzers AG, Liechtenstein*

1999



ELSEVIER

Amsterdam – Lausanne – New York – Oxford – Shannon – Singapore – Tokyo

ELSEVIER SCIENCE B.V.  
Sara Burgerhartstraat 25  
P.O. Box 211, 1000 AE Amsterdam, The Netherlands

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First edition 1984  
Second impression 1985  
Third impression 1987  
Fourth impression 1996  
Second, revised edition 1999

Library of Congress Cataloging in Publication Data  
A catalog record from the Library of Congress has been applied for.

ISBN: 0-444-50103-7

♻ The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).  
Printed in The Netherlands.

## DEDICATION

This monograph is dedicated to three distinguished personalities who have played a decisive role in the development and spread of the industrial manufacture of thin films produced under vacuum by physical methods:

Prof. Dr. Dr.h.c. Max Auwärter  
Founder and first President  
of the BALZERS AG

Dr. Albert Ross  
President of the BALZERS AG

Dr. Otto Winkler  
Director of the BALZERS AG

Hans. K. Pulker

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FOREWORD  
of the First Edition

The subject matter of this book *COATINGS ON GLASS* includes a wealth of information for physicists, chemists and engineers who need to know more about thin films for research purposes, or who want to use this special form of solid material to achieve a variety of application-oriented goals.

This particular publication is exceptional because the author makes available his extensive theoretical and practical experience which has been acquired over more than 20 years of intensive work on thin films. He has been concerned with all details that have an influence on the final product and can thus describe with great thoroughness the properties of all glass-type substrates, dealing also with very difficult questions concerning surface physics.

Glass can be produced by a variety of methods. The manufacturing process and the chemical composition determine how resistant a particular glass is to its environment. There are also different processes for finishing the surface of glass and this, together with the two aforementioned factors, determines the surface characteristics. Apart from inorganic glass also organic glass and plastic materials are considered.

Today there are two preferred groups of methods for the production of thin films: Chemical vapour deposition and physical vapour deposition under vacuum; the three major technologies of the latter being sputtering, evaporation, and ion plating. These are discussed in detail. The author's wide experience allows him to give many valuable tips in the discussion of how to produce a vacuum with a desired residual gas atmosphere using appropriate vacuum techniques. He has also studied mechanical and optical film properties as well as film thickness measurement methods, and this too is included in the book. Information on calculation methods which allow complex film systems to be developed is also given. Precise calculations and extremely accurate measurements are the basis for the production of thin films in computer controlled coating systems.

Applications of thin films are also given an important place in the book. The company in which the author works is world famous for its thin film products.

In summary, this work could be called a sort of formulary on the subject of glass and thin films written by a scientist for scientists and technical people. It goes beyond the subject matter indicated by the title, filling in the gap which has existed until now in the available technical literature.

M. Auwärter

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PREFACE  
of the First Edition

Hans K. Pulker is an old friend for whom I have always had the highest regard. He is also a thin-film worker with a well-deserved international reputation for careful and original scientific work. I was delighted, therefore, when I heard that he was in the course of writing a book on coatings on glass. It is a source of great satisfaction and pleasure to me to write the preface so that I can be associated even in this minor way with what promises to be one of the standard works of reference in this important and ever-growing field.

All of us who work in the field of thin films have had more than our share of frustrating experiences with apparently inexplicable failures of a coating process. Frequently these involve well-developed techniques which have been running quietly and efficiently for some time. Suddenly coatings no longer adhere to the substrates although we are apparently following our standard procedure. Or stains appear in coatings on carefully prepared substrates. Sometimes absorption is high when it should be low, or cloudy scattering is apparent. Occasionally the problems are even more insidious, appearing only at a much later stage when components have already been supplied to a customer and are already in an optical system. I dwell on optical coatings because that is my own particular field but similar problems plague other areas of thin-film work. Apart from the weather, bad luck has often seemed the only reason for such troubles and even lucky charms have been seen in coating shops.

The past decade has seen considerable changes. We still suffer from unforeseen problems but gradually we are coming to understand the complex physics and chemistry governing the phenomena. We are used to dealing with thin films on a macroscopic scale and indeed it is their macroscopic properties in the main that we seek to produce with our coatings. These macroscopic properties, however, are entirely determined by film microstructure and it is only when we begin to understand the microstructure on an atomic scale and the physics and chemistry associated with it that we can appreciate the source of our problems and begin constructively to overcome them and to advance.

Films and substrates are held together by very short range forces, the bonds between one atom and the next. The mechanical properties of the films, including their intrinsic stress, are ultimately determined by these same bonds and their interaction with the microstructure. Their behaviour at surfaces can be greatly modified by minute quantities of impurity and they can be blocked completely by one molecular layer of contaminant. Adsorption is a particularly important process in thin films which must also be understood on an atomic scale.

Our understanding of film systems must begin with the nature of the surface on which they are deposited. Glass surfaces, the subject of this book, are particularly complex because of the nature of glass itself. Because of the gross effect of even

minute contamination, cleaning is extremely important. Significant sections of the book are devoted to these topics followed by surveys of the bewilderingly extensive array of processes for thin-film deposition, techniques for measurement and characterization, fundamental film properties and optical coatings.

Hans K. Pulker himself has made notable contributions to the improvement of our understanding of the physics and chemistry of thin films and to deposition processes. The subject is vast and the literature extensive but scattered through journals in many different disciplines. It is difficult to know where to begin a study of the subject. I should say that it *was* difficult because the situation has changed with the publication of this book.

H. A. Macleod

AUTHOR'S PREFACE  
of the First Edition

When the Elsevier Scientific Publishing Company first invited me to write a monograph on *COATINGS ON GLASS*, I was hesitant because of the enormous amount of work involved. However, after critically examining my own collection of literature on thin films and glass, and considering the amount of pertinent information available in the scientific libraries of both the Balzers AG and the Swiss Federal Institute of Technology in Zürich, I changed my mind.

Dr. A. Ross, President of the Balzers AG until the end of 1982, encouraged me with the project, and his successor Dr. G. Zinsmeister, continued this support. I was thus able to notify the publisher that I could accept their invitation.

Much of the material in the present work was originally prepared for lectures presented at the Institute of Physical Chemistry at the University of Innsbruck in Austria. However, to limit the length of the work some elementary material has been eliminated, leaving room for new information and details on technical processes so that the topic could be covered comprehensively. It was not my intention to publish in-depth studies of any particular area but rather to provide a well founded background from which individual interests in various directions could be developed by the specialist or the newcomer to the field.

Following a history of glass and films presented as an introduction in Chapter 1, the Chapters 2 to 4 of this monograph attempt to outline the present-day knowledge of glass, with particular attention given to such factors as structure and composition and how they influence the properties of the material. The condition of the substrate surface is of primary importance in the coating process and therefore the generation, cleaning and properties of the glass surface is treated extensively. In addition to inorganic glass, organic glass and plastics are also discussed.

There has been a close interrelation between glass and thin films for a long time. Thin films on glass are used both for scientific and industrial purposes. One of the most important requirements placed on industrial coatings is that they adhere well to the substrate surface, particularly if they are to be subjected to extreme environmental conditions. This topic is treated in Chapter 5.

There are many chemical and physical methods for producing thin films with reproducible characteristics on a variety of substrates. A distinction is also made between wet and dry film formation methods. In some of these methods the depositions are carried out in air at normal atmospheric pressure or in the presence of protective gases and still others are carried out under vacuum. However, not all these methods are suitable for coating glass substrates because of their insulating nature and the relatively low thermal stability of many inorganic and practically all organic glasses. In Chapter 6 suitable coating methods and the plants for them are described. The various methods for the determination of film thickness and deposition rate are treated in Chapter 7.

Thin films generally have large surface to volume ratios, and consequently the extended surface usually has a large influence on the film properties. Structure, microstructure, chemical composition, mechanical and optical properties, etc. of films deposited by different methods are described and discussed in Chapter 8.

Finally, in Chapter 9, relevant industrial and scientific applications for thin films on glass are given.

The bibliography for this monograph does not pretend to be more than a selected one. The references cited are mainly original investigations, but review articles and books containing supplementary references are also listed.

Acknowledgements are made to Prof. Dr. M. Auwärter and Dr. A. Ross (Balzers AG) as well as to Dr. H. Dislich (Schott Glaswerke) for valuable discussions and advice.

Further thanks are given to the scientists and technologists of various other industrial companies and scientific institutes who gave their support to the author, making available many figures and valuable information. Here particularly must be mentioned: Dr. Ian Seddon (Optical Coating Labs. Inc., Santa Rosa, CA, USA), Dr. G. Kienel and Ing. G. Deppisch (Leybold Heraeus GmbH, Köln, FRG), Dr. K. Deutscher (Leitz, Wetzlar, FRG), Dr. H. Bach (Schott, Mainz, FRG), Dr. F. Geotti-Bianchini (Stazione Sperimentale del Vetro, Murano-Venezia, Italy), Dr. C. Misiano (Selenia SpA, Roma, Italy), Prof. Dr. R. W. Hoffman (Case Western Reserve University, Cleveland, OH, USA), Prof. Dr. R.Th. Kersten (Technische Universität, Berlin), Prof. Dr. H. A. Macleod (Optical Sciences Center, University of Arizona, Tucson, AR, USA) and Dr. E. Pelletier (Ecole Nationale Supérieure de Physique, Marseille, France).

The author is also very much obliged to friends and colleagues for their engaged assistance during the preparation of this book. Special thanks are due to Dr. O. Winkler, Dr. E. Ritter, Dr. G. Trabesinger and Prof. H.A. Macleod for critical reading of the manuscript and for their stimulating comments, and to Mr. W. Frischknecht (Fri-Grafik, Vaduz, Liechtenstein) for drawing most of the figures and to Mr. and Mrs. L. Hilty (printing office, Schaan, Liechtenstein) for preparing the camera-ready manuscript.

Last not least it is a pleasure to acknowledge the assistance of the staff of Elsevier Science Publishers in Amsterdam and to thank Mrs. A. Ruhe-Lodge, Miss K. O'Day and Dr. A.J. Perry for language corrections.

Hans. K. Pulker

## AUTHOR'S PREFACE

The importance of inorganic and organic glass in numerous technical and scientific applications is rapidly growing. Glass in its broadest sense is an important substrate for thin film coatings. Chemistry and physics occupy a central position in the treatment of both materials. It is therefore assumed that the reader – students, engineers, scientists – already has suitable knowledge in this field.

Coatings on glass and polymers are found today in an increasing number ranging from the architectural and automotive sector, the diverse applications in technical and scientific optics to various sophisticated high-tech structures. Coatings are used in practically all optical and electro-optical devices. They are frequently the ultimate determinants of performance.

The first edition of this book started in 1984 and had four unchanged impressions 1984, 1985, 1987 and 1996. It was translated into Chinese and printed in China 1987. Now its content is revised and updated. The emphasis was and still is pragmatic providing closer insight into the coating business and the properties of glass and thin films, particularly for optical purposes.

There are many people that have given me their support and advice, and the names of the people noted here have played a major role in the success of this edition.

I would like to acknowledge the support given to me by the management of the Balzers and Leybold Group during preparation of the manuscript, in particular, Mr. Andreas Vogt. I also thank Dr. Elmar Ritter and Dr. Günter Bräuer, also at Balzers and Leybold, and Dr. Angela Duparré at the Fraunhofer Institute in Jena, Germany for their unflagging encouragement during the writing of the manuscript.

My friend, Dr. Carlo Misiano, President of the Centro Tecnologie del Vuoto in Carsoli, Italy as well as my colleagues at the University of Innsbruck, Austria were also very generous with their time and, through many stimulating conversations, helped me work through numerous questions that came up during the writing.

Special thanks are due to Mrs. Iris M. Kündig-Hänni, who gave me critical support in the technical preparation of the manuscript. Dr. Nanning van der Hoop, Publication Manager for Physics and Astronomy at Elsevier Science BV in Amsterdam, The Netherlands, deserves sincere thanks for his suggestion to actually undertake the update of this book.

Finally, my deepest thanks to my wife, Marianne, who has supported me with patience, quiet encouragement and understanding during the writing.

Hans K. Pulker

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## 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