

Handbook of Optical Constants of Solids

Edited by

EDWARD D. PALIK

Naval Research Laboratory
Washington, D.C.



ACADEMIC PRESS, INC.
Harcourt Brace Jovanovich, Publishers

Boston San Diego New York
London Sydney Tokyo Toronto

Contents

List of Contributors	xv
Preface	xvii

Part I DETERMINATION OF OPTICAL CONSTANTS

Chapter 1	Introductory Remarks	3
	EDWARD D. PALIK	
	I. Introduction	3
	II. The Chapters	4
	III. The Critiques	5
	IV. The Tables	6
	V. The Figures of the Tables	7
	VI. General Remarks	8
	References	9
Chapter 2	Basic Parameters for Measuring Optical Properties	11
	ROY F. POTTER	
	I. Introduction	11
	II. Intrinsic Material Parameters in Terms of Optical Constants	16
	III. Reflectance, Transmittance, and Absorptance of Layered Structures	18
	IV. The General Lamelliform — Phase Coherency Throughout	19
	V. The General Lamelliform — Phase Incoherency in Substrate	21
	VI. Summary	24
Appendix A.	Basic Formulas for Fresnel Coefficients	24
Appendix B.	General Formulas for the Case of a Parallel-Sided Slab	25
Appendix C.	Reflectance, R_{jk} at $j-k$ Interface	26
Appendix D.	Reflectance of Single Layer on Each Side of a Slab and Single Layer on Either Side of a Slab	26
Appendix E.	Critical Angle of Incidence	30
	Definition of Terms	33
	References	34
Chapter 3	Dispersion Theory, Sum Rules, and Their Application to the Analysis of Optical Data	35
	D. Y. SMITH	
	I. Introduction	36
	II. Optical Sum Rules and Their Physical Interpretation	36

III.	Finite-Energy Sum Rules	45
IV.	Sum Rules for Reflection Spectroscopy	51
V.	Analysis of Optical Data and Sum-Rule Applications	55
VI.	Summary	64
	References	64
Chapter 4	Measurement of Optical Constants in the Vacuum Ultraviolet Spectral Region	69
	W. R. HUNTER	
I.	Introduction	69
II.	General Discussion of Reflectance Methods	70
III.	Reflectance Method for Two Media	85
	References	87
Chapter 5	The Accurate Determination of Optical Properties by Ellipsometry	89
	D. E. ASPNES	
I.	Reflection Techniques; Background and Overview	89
II.	Measurement Configurations	92
III.	Accurate Determination of Optical Properties: Overlayer Effects	96
IV.	Living with Overlayers	99
V.	Eliminating Overlayers	102
VI.	Bulk and Thin-Film Effects; Effective-Medium Theory	104
VII.	Conclusion	108
	References	110
Chapter 6	Interferometric Methods for the Determination of Thin-Film Parameters	113
	JOSEPH SHAMIR	
I.	Introduction	113
II.	Basic Principles	114
III.	Nonlaser Interferometers	117
IV.	Kösters-Prism Interferometers	123
V.	A Self-Calibrating Method	126
VI.	Surface Effects	131
VII.	Conclusions	132
	References	133
Chapter 7	Thin-Film Absorptance Measurements Using Laser Calorimetry	135
	P. A. TEMPLE	
I.	Introduction	135
II.	Single-Layer Films	138
III.	Wedged-Film Laser Calorimetry	139
IV.	Electric-Field Considerations in Laser Calorimetry	143
V.	Entrance versus Exit Surface Films	147

VI.	Experimental Determination of α_f , a_{af} , and a_{fs}	149
	References	153
Chapter 8	Complex Index of Refraction Measurements at Near-Millimeter Wavelengths	155
	GEORGE J. SIMONIS	
I.	Introduction	155
II.	Fourier Transform Spectroscopy	156
III.	Free-Space Resonant Cavity	161
IV.	Mach-Zehnder Interferometer	163
V.	Direct Birefringence Measurement	164
VI.	Overmoded Nonresonant Cavity	165
VII.	Crystal Quartz as Index Reference	165
VIII.	Conclusion	167
	References	167
Chapter 9	The Quantum Extension of the Drude-Zener Theory in Polar Semiconductors	169
	B. JENSEN	
I.	Introduction	169
II.	Quantum Theory of Free-Carrier Absorption	172
III.	Theoretical Results	174
IV.	Comparison with Experimental Data	176
	Appendix	187
	References	188
Chapter 10	Interband Absorption—Mechanisms and Interpretation	189
	DAVID W. LYNCH	
I.	Introduction	189
II.	One-Electron Model	190
III.	Electron-Hole Interaction, Excitons	198
IV.	Local Field Effects	203
V.	Examples	204
	References	210
	General References	211
Chapter 11	Optical Properties of Nonmetallic Solids for Photon Energies below the Fundamental Band Gap	213
	SHASHANKA S. MITRA	
I.	Introduction	213
II.	Infrared Dispersion by Polar Crystals	215
III.	Kramers-Kronig Dispersion Relations	227
IV.	Determination of Absorption Coefficient in the Intermediate Region	229
V.	Absorption Coefficient in the Transparent Regime	230
VI.	Multiphonon Absorption	232

VII.	Infrared Absorption by Defects and Disorders	254
VIII.	Infrared Dispersion by Plasmons	263
	References	267

Part II CRITIQUES

Subpart 1 Metals

	Comments on the Optical Constants of Metals and an Introduction to the Data for Several Metals	275
	DAVID W. LYNCH AND W. R. HUNTER	

I.	Introduction	275
II.	Anomalous Skin Effect	277
	References	279
III.	Copper (Cu)	280
	References	280
IV.	Gold (Au)	286
	References	287
V.	Iridium (Ir)	296
	References	296
VI.	Molybdenum (Mo)	303
	References	304
VII.	Nickel (Ni)	313
	References	314
VIII.	Osmium (Os)	324
	References	324
IX.	Platinum (Pt)	333
	References	334
X.	Rhodium (Rh)	342
	References	342
XI.	Silver (Ag)	350
	References	351
XII.	Tungsten (W)	357
	References	358

	The Optical Properties of Metallic Aluminum	369
	D. Y. SMITH, E. SHILES, AND MITIO INOKUTI	

I.	General Features	369
II.	Optical Measurements and Sample Conditions	372
III.	Tabulated Data	377
	References	383

Subpart 2 Semiconductors

	Cadmium Telluride (CdTe)	409
	EDWARD D. PALIK	
	References	413

Gallium Arsenide (GaAs)	429
EDWARD D. PALIK	
References	432
Gallium Phosphide (GaP)	445
A. BORGHESI AND G. GUIZZETTI	
References	449
Germanium (Ge)	465
ROY F. POTTER	
References	469
Indium Arsenide (InAs)	479
EDWARD D. PALIK AND R. T. HOLM	
References	481
Indium Antimonide (InSb)	491
R. T. HOLM	
References	494
Indium Phosphide (InP)	503
O. J. GLEMBOCKI AND H. PILLER	
References	506
Lead Selenide (PbSe)	517
G. BAUER AND H. KRENN	
References	518
Lead Sulfide (PbS)	525
G. GUIZZETTI AND A. BORGHESI	
References	528
Lead Telluride (PbTe)	535
G. BAUER AND H. KRENN	
References	538
Silicon (Si)	547
DAVID F. EDWARDS	
References	552

Silicon (Amorphous) (α-Si)	571
H. PILLER	
References	573
Silicon Carbide (SiC)	587
W. J. CHOYKE AND EDWARD D. PALIK	
References	589
Zinc Sulfide (ZnS)	597
EDWARD D. PALIK AND A. ADDAMIANO	
References	602
Subpart 3 Insulators	
Arsenic Selenide (As_2Se_3)	623
D. J. TREACY	
References	625
Arsenic Sulfide (As_2S_3)	641
D. J. TREACY	
References	644
Cubic Carbon (Diamond)	665
DAVID F. EDWARDS AND H. R. PHILIPP	
References	668
Lithium Fluoride (LiF)	675
EDWARD D. PALIK AND W. R. HUNTER	
References	678
Lithium Niobate ($LiNbO_3$)	695
EDWARD D. PALIK	
References	697
Potassium Chloride (KCl)	703
EDWARD D. PALIK	
References	706

Silicon Dioxide (SiO₂), Type α (Crystalline)	719
H. R. PHILIPP	
References	721
Silicon Dioxide (SiO₂) (Glass)	749
H. R. PHILIPP	
References	752
Silicon Monoxide (SiO) (Noncrystalline)	765
H. R. PHILIPP	
References	766
Silicon Nitride (Si₃N₄) (Noncrystalline)	771
H. R. PHILIPP	
References	772
Sodium Chloride (NaCl)	775
J. E. ELDRIDGE AND EDWARD D. PALIK	
References	779
Titanium Dioxide (TiO₂) (Rutile)	795
M. W. RIBARSKY	
References	798