Fundamentals of

Dispersive Optical Spectroscopy Systems

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SPIE PRESS
Bellingham, Washington USA

Library of Congress Cataloging-in-Publication Data

Neumann, Wilfried, author.
Fundamentals of dispersive optical spectroscopy systems/Wilfried Neumann
pages cm
Includes bibliographical references and index.
ISBN 978-0-8194-9824-3
1. Optical spectroscopy. 2. Optical spectrometers. I. Title.
QC454.O66N48 2014
535.8'4 dc23
2013032275

Published by

SPIE The International Society for Optical Engineering
P.O. Box 10
Bellingham, Washington 98227-0010 USA
Phone: +1 360 676 3290
Fax: +1 360 647 1445
Email: spie@spie.org
Web: http://spie.org

Printed in the United States of America.
First printing

SPIE.

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Preface

My search for universal and comprehensive literature on dispersive optical spectroscopy revealed many gaps. The books on very basic information are rather theoretical and dig deep into arithmetic derivations to calculate spectrometers, illumination, and detection. The books on the different applications of optical spectroscopy are mainly "cookbooks" and do not explain why something should be done in a certain way. Books with comprehensive content are available from the vendors of dispersers, spectrometers, detectors, and systems—they naturally feature the advantages of the supported products but offer no overall view.

For more than twenty years, I have calculated and delivered special dispersive spectroscopy systems for different applications. In the time between inquiry and decision, the customers wanted to justify my presentation and compare it. A common problem was finding useful references that could be used to verify my calculations and predictions. So, again and again, I wrote long letters combining the different parameters of the project presented. Several of my customers—industrial project managers as well as researchers—not only acknowledged the proposals but also often used the papers to check the instrumental performance at delivery. Because the proposals fit the requirements and the predictions were at least reached, their confidence was earned. Customers used my papers for internal documentation and teaching. Several asked me to provide the know-how in a general, written database in order to close the gap between theory, practice, and applications. After my retirement from regular work, I did just that, and published my writing on my homepage (www.spectra-magic.de). Now, the content has been improved and extended into a pair of printed books, the first of which you are reading now.

The aim of this book is to supply students, scientists, and technicians entering the field of optical spectroscopy with a complete and comprehensive tutorial; to offer background knowledge, overview, and calculation details to system designers for reference purpose; and to provide an easy-to-read compendium for specialists familiar with the details of optical spectroscopy.

Acknowledgments

My thanks are first addressed to my wife, Heidi, for her patience during the months spent investigating, reviewing, and writing. I also thank those who urged me to start writing in the first place and who collected data and calculations. The trigger to turn the homepage into written books came from Dr. Karl-Friedrich Klein, who kept me going and contacted SPIE. The section on fiber optics was supported by Joachim Mannhardt, who provided specifics and added features and ideas. After the manuscript was given to SPIE, external reviewers spent much effort on the content, providing corrections and suggestions for improvement; that valuable support came from Mr. Robert Jarratt and Dr. Alexander Sheeline. Last but not least, I´d like to thank Tim Lamkins, Scott McNeill, and Kerry McManus Eastwood at SPIE for the work they invested into the project.

I hope that readers will find useful details that further their interest or work.

Wilfried Neumann
May 2014

Glossary of Symbols and Notation

A	Absorbance (extinction) in photometric absorption measurements
A	Geometric area
A	Light angle inside a prism
ADC (A/D-C)	Analog-to-digital converter
A_{iG}	Effective disperser area at a given disperser angle
A_{iM}	Illuminated area of the focusing mirror
B	Bandwidth
C	Capacity
C	Contrast; ratio of useful signal/disturbance
c_0	Speed of light
CCD	Charge-coupled device
d	Deflection angle at the prism
d	Dispersed beam after a grating
D^*	Numeric capability of an IR detector for the recovery of low signals
dB	Decibel
d_x	Focus displacement after thermal change
d_y	Focus increase after thermal change
e	Base of the natural logarithm
E	Deformation factor at the exit of a spectrometer
e^-	Electron
$E_{(\lambda)}$	Irradiance of a light beam on a normalized surface
el	Elbow angle
eV	Electron volt
f	Focal length
f	Frequency
f_c	Angular frequency
FSR	Free spectral range
FWHM	Full width at half maximum
h	Planck's constant (6.626×10^{-34} Js)

h	Slit height
H	Total aberration
hb	Number of pixels binned together
I	Parallel incident beam to grating or prism
i_1	Angle of the prism's incident light related to N
J	Joule
k	Absorption coefficient of a material
k	Boltzmann's constant (1.381×10^{-23} JK^{-1})
k	Grating constant for the distance of the grating lines
K	Kelvin
K	Thermal dilatation coefficient
L	Inductivity
L	Luminosity, light flux in spectrometers
$L_{(\lambda)}$	Radiance
LN	Liquid nitrogen
m	Modulation factor in lifetime measurements by phase/modulation
m	Spectral order number
M	Magnification factor
M	Radiant emittance/exitance
MCP	Microchannel plate; also, microchannel-plate image-intensifier system
m_s	Minimum slit width
n	*f*-number
n	Refractive index
n	Total number of lines in a grating
N	The normal of a grating or prism
O	Aberration
O_1	Basic aberration
O_{ss}	Additive aberration
P	Power
PMT	Photomultiplier tube
PPS	Pulses per second; also, events per second
PSD	Phase-sensitive detector (in the lock-in); also, position-sensitive (counting) detector
Q	Energy of radiation R; also, the numerical resolution
Q	Ratio of the numerical resolution R_r/R_p
Q	Quality factor
QE	Quantum efficiency
r	Radius of curved slits; also, the distance of the slit to the instrument's center
R	Normalized reflectance of a sample
R	Numeric resolution
R	Resistance

RD	Reciprocal dispersion
ROI	Region of interest
R_p	Theoretical resolution of a dispersing element
r_p	Absolute value of parallel polarization
r_s	Absolute values of perpendicular polarization
R_r	Real experimental resolution
s	Constant of thermal diffusion
SL	Number of vertical lines of a CCD
SNR (S/N-R)	Signal-to-noise ratio
sr	Steradian
SR	Number of horizontal register pixels of a CCD
STD	Standard deviation
T	Temperature; also, thermal change
T	Normalized transmission in photometric applications
w	Median distance of a mirror to the center line or grating center axis
W	Active grating or mirror width
W	Electrical or optical work
x	Geometric dilation as a function of thermal change
x	Half the inclusion angle at the grating
y	Geometric increase of the focal spot as a function of thermal change and dilatation
α	Angle of the light illuminating the grating or prism with respect to N
β	Angle of the diffracted or refracted light leaving the disperser with respect to N
δ	Inclusion angle of the light at the disperser originating from the lateral distance and width of the mirrors
δ	Phase angle or phase shift ellipsometry (SE)
Δ	Imaginary part of ellipsometric data
ε_1	Angle of the grating-impinging beam
ε_2	Angle of the beam leaving the grating
ι	Internal off-axis angle
ι_h	Horizontal off-axis angle in a spectrometer
ι_v	Vertical off-axis angle in a spectrometer
λ	Wavelength
ν	Oscillation frequency of a light wave
$\tilde{\nu}$	Frequency of a light wave presented as a wavenumber
ρ	Complex result of ellipsometric data
σ	Statistical parameter often used for deviations
τ	Time constant
Φ	Angle of sample illumination in ellipsometry
Φ	Median grating angle

Φ	Phase angle/phase shift in phase/modulation lifetime measurements
Φ	Radiant power/flux
Ψ	Real part of ellisometric data
ω	Angular frequency
ω	Normalized cone angle of illumination
Ω	Acceptance angle
Ω	Real and normalized aperture of a spectrometer; also, light-guiding factor