Fundamentals of Dispersive Optical Spectroscopy Systems
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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_c Focus displacement after thermal change
d_p Focus increase after thermal change
e Base of the natural logarithm
E Deformation factor at the exit of a spectrometer
e^{-} Electron
E_{\lambda}(\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 \times 10^{-34} \text{ Js})
<table>
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<tr>
<th>Symbol</th>
<th>Definition</th>
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<tr>
<td>$h$</td>
<td>Slit height</td>
</tr>
<tr>
<td>$H$</td>
<td>Total aberration</td>
</tr>
<tr>
<td>$hb$</td>
<td>Number of pixels binned together</td>
</tr>
<tr>
<td>$I$</td>
<td>Parallel incident beam to grating or prism</td>
</tr>
<tr>
<td>$i_1$</td>
<td>Angle of the prism's incident light related to $N$</td>
</tr>
<tr>
<td>$J$</td>
<td>Joule</td>
</tr>
<tr>
<td>$k$</td>
<td>Absorption coefficient of a material</td>
</tr>
<tr>
<td>$k$</td>
<td>Boltzmann’s constant $(1.381 \times 10^{-23} \text{J}K^{-1})$</td>
</tr>
<tr>
<td>$k$</td>
<td>Grating constant for the distance of the grating lines</td>
</tr>
<tr>
<td>$K$</td>
<td>Kelvin</td>
</tr>
<tr>
<td>$K$</td>
<td>Thermal dilatation coefficient</td>
</tr>
<tr>
<td>$L$</td>
<td>Inductivity</td>
</tr>
<tr>
<td>$L$</td>
<td>Luminosity, light flux in spectrometers</td>
</tr>
<tr>
<td>$L_{(\lambda)}$</td>
<td>Radiance</td>
</tr>
<tr>
<td>$LN$</td>
<td>Liquid nitrogen</td>
</tr>
<tr>
<td>$m$</td>
<td>Modulation factor in lifetime measurements by phase/modulation</td>
</tr>
<tr>
<td>$m$</td>
<td>Spectral order number</td>
</tr>
<tr>
<td>$M$</td>
<td>Magnification factor</td>
</tr>
<tr>
<td>$M$</td>
<td>Radiant emittance/exitance</td>
</tr>
<tr>
<td>MCP</td>
<td>Microchannel plate; also, microchannel-plate image-intensifier system</td>
</tr>
<tr>
<td>$m_s$</td>
<td>Minimum slit width</td>
</tr>
<tr>
<td>$n$</td>
<td>$f$-number</td>
</tr>
<tr>
<td>$n$</td>
<td>Refractive index</td>
</tr>
<tr>
<td>$n$</td>
<td>Total number of lines in a grating</td>
</tr>
<tr>
<td>$N$</td>
<td>The normal of a grating or prism</td>
</tr>
<tr>
<td>$O$</td>
<td>Aberration</td>
</tr>
<tr>
<td>$O_1$</td>
<td>Basic aberration</td>
</tr>
<tr>
<td>$O_{ss}$</td>
<td>Additive aberration</td>
</tr>
<tr>
<td>$P$</td>
<td>Power</td>
</tr>
<tr>
<td>PMT</td>
<td>Photomultiplier tube</td>
</tr>
<tr>
<td>PPS</td>
<td>Pulses per second; also, events per second</td>
</tr>
<tr>
<td>PSD</td>
<td>Phase-sensitive detector (in the lock-in); also, position-sensitive (counting) detector</td>
</tr>
<tr>
<td>$Q$</td>
<td>Energy of radiation $R$; also, the numerical resolution</td>
</tr>
<tr>
<td>$Q$</td>
<td>Ratio of the numerical resolution $R_p/R_p$</td>
</tr>
<tr>
<td>$Q$</td>
<td>Quality factor</td>
</tr>
<tr>
<td>QE</td>
<td>Quantum efficiency</td>
</tr>
<tr>
<td>$r$</td>
<td>Radius of curved slits; also, the distance of the slit to the instrument’s center</td>
</tr>
<tr>
<td>$R$</td>
<td>Normalized reflectance of a sample</td>
</tr>
<tr>
<td>$R$</td>
<td>Numeric resolution</td>
</tr>
<tr>
<td>$R$</td>
<td>Resistance</td>
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**Glossary of Symbols and Notation**

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
$\alpha$  Angle of the light illuminating the grating or prism with respect to N
$\beta$  Angle of the diffracted or refracted light leaving the disperser with respect to N
$\delta$  Inclusion angle of the light at the disperser originating from the lateral distance and width of the mirrors
$\delta$  Phase angle or phase shift ellipsometry (SE)
$\Delta$  Imaginary part of ellipsometric data
$\varepsilon_1$  Angle of the grating-impinging beam
$\varepsilon_2$  Angle of the beam leaving the grating
$\iota$  Internal off-axis angle
$\iota_h$  Horizontal off-axis angle in a spectrometer
$\iota_v$  Vertical off-axis angle in a spectrometer
$\lambda$  Wavelength
$\nu$  Oscillation frequency of a light wave
$\tilde{\nu}$  Frequency of a light wave presented as a wavenumber
$\rho$  Complex result of ellipsometric data
$\sigma$  Statistical parameter often used for deviations
$\tau$  Time constant
$\Phi$  Angle of sample illumination in ellipsometry
$\Phi$  Median grating angle
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tr>
<td>$\Phi$</td>
<td>Phase angle/phase shift in phase/modulation lifetime measurements</td>
</tr>
<tr>
<td>$\Phi$</td>
<td>Radiant power/flux</td>
</tr>
<tr>
<td>$\Psi$</td>
<td>Real part of ellisometric data</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Angular frequency</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Normalized cone angle of illumination</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>Acceptance angle</td>
</tr>
<tr>
<td>$\Omega$</td>
<td>Real and normalized aperture of a spectrometer; also, light-guiding factor</td>
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