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Chiral Nanophotonics

Chiral Optical Properties of Plasmonic Systems

Springer

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To Michèle

Preface

Chirality is a fascinating geometrical property: We have two objects that look similar, because they are mirror images of each other, but when we try to superpose them, we realize that they are not the same. This observation can also be confirmed experimentally: There are several spectroscopy methods that are sensitive to the handedness of such chiral objects. Therefore, the two enantiomorphs of a chiral object differ not only from a mathematical, but also from a physical point of view. Although chirality seems to be a very special kind of missing symmetry, many structures that can be found in nature—from small biomolecules to the shape of snail shells—are chiral.

Most research regarding the properties of chiral objects has been conducted in the field of stereochemistry thus far. In chemistry, molecules are commonly chiral, and their handedness is of utmost importance for their interaction. In physics, however, chirality is not that commonly dealt with. In many optics textbooks, for example, the discussion is limited to the rotation of linear polarization in chiral media.

In the field of plasmonics, which deals with sub-wavelength metallic nanostructures of arbitrarily complex shape, it is well-known that geometry and shape of such structures control their optical response. Therefore, the combination with chirality, which is also a geometrical property, seems to be natural.

In this book, we will discuss the chiral properties of nanoscopic plasmonic system. This discussion not only covers the origin of chiral far-field responses such as circular dichroism or optical activity, but also examines the chiral near-field response. To obtain this, we discuss the chiral properties of electromagnetic fields and study how plasmonic nanostructures can affect them. Interestingly, we find that these responses are rather different: No direct connection between the common chiral far-field responses and the occurrence of chiral near-fields can be drawn.

This book is based on my Ph.D. thesis “Chiral Plasmonic Near-Field Sources: Control of Chiral Electromagnetic Fields for Chiroptical Spectroscopies,” which has been conducted at the University of Stuttgart in the group of Prof. Dr. Harald Giessen [1]. I would like to thank Prof. Giessen for his ongoing support of my work and many helpful scientific discussions. Furthermore, I would like to thank Jun.-Prof. Dr. Maria Fyta for co-supervising my work and Prof. Dr. Martin Dressel for heading the examination committee.

I thank Prof. Giessen for initializing the contact with Springer, which finally led to this book. Compared to my thesis, the book has been updated and extended to cover the latest research in the highly active field of chiral plasmonics. Parts of this book have already been published in scientific journals. Chapter 5 and parts of Chap. 6 are based on [2]. Chapter 7 (except for the second part of Sect. 7.3) is adapted with permission from [3]. Copyright 2012 Optical Society of America. Sections 8.1 and 8.2 are adapted with permission from [4]. Copyright (2014) American Chemical Society. Section 8.3 is adapted with permission from [5]. Copyright (2016) American Chemical Society.

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Stuttgart, Germany Martin Schäferling

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Contents

Constants, Symbols, and Acronyms

Constants

c	Speed of light in vacuum, $c = 299{,}792{,}458\ \mathrm{m\ s^{-1}}$
e	Elementary charge, $e = 1.602 \times 10^{-19}\ \mathrm{C}$
ε_0	Vacuum permittivity, $\varepsilon_0 = 8.854 \times 10^{-12}\ \mathrm{F\ m^{-1}}$
μ_0	Vacuum permeability, $\mu_0 = 4\pi \times 10^{-7}\ \mathrm{N\ A^{-2}}$

Symbols

A	Absorbance
a	Absorption rate of a single molecule in an electromagnetic field (see (4.18))
a^*	Combined absorption rate of two molecules (see Sect. 6.2)
α	Electric dipole polarizability
$\boldsymbol{B}$	Magnetic field
$\boldsymbol{\mathcal{B}}$	Magnetic field (real part)
β_b, β_e	Prefactors of U_b and U_e in the equation for a (see (4.19))
χ	Magnetic dipole polarizability
C	Optical chirality density (see (4.7))
$\boldsymbol{D}$	Electric displacement field
d	distance between oscillators in the Born–Kuhn model (see Sect. 2.2.2.2)
$\boldsymbol{E}$	Electric field
$\boldsymbol{\mathcal{E}}$	Electric field (real part)
ε	Relative electric permittivity
ϵ	Molar extinction coefficient
g	Dissymmetry factor (see (4.21))
g^*	Combined dissymmetry factor of two molecules (see Sect. 6.2)
γ	Damping in oscillator models

Γ	Chirality parameter of the Drude–Born–Fedorov chiral constitutive equations (see (2.44))
$\boldsymbol{H}$	Magnetic field strength
$\boldsymbol{J}$	Jones vector
$\boldsymbol{j}$	Free current
k	Wave number
κ	Chirality parameter of the standard chiral constitutive equations (see (2.48))
l	Path length in a chiral medium
$\boldsymbol{m}$	Magnetic dipole moment
m^*	Effective electron mass
μ	Relative magnetic permeability
N	Number of particles described by an oscillator model
n	Refractive index
$\boldsymbol{P}$	Macroscopic polarization
$\boldsymbol{p}$	Electric dipole moment
ϕ	Phase
φ	Polarization angle
$\boldsymbol{\Phi}_{\mathrm{C}}$	Optical chirality flux (see (4.2))
R	Reflectance
ϱ	Free charge
T	Transmittance
$\boldsymbol{u}$	Displacement of a harmonic oscillator
U_{b}	Time-averaged magnetic energy density (see (4.17))
U_{e}	Time-averaged electric energy density (see (4.16))
ω	Angular frequency
ω_0	Resonance frequency
ω_{c}	Chiral coupling parameter in the Born–Kuhn model (see Sect. 2.2.2.2)
ω_{p}	Plasma frequency (see (2.12))
Ω	Abbreviation used in the Born–Kuhn model, $\Omega := \sqrt{\omega_0^2 - \hat{\imath}\gamma\omega - \omega^2}$ (see (2.36))
ξ	Mixed electric-magnetic dipole polarizability

Vectors are printed **bold**. Tensorial quantities are typeset with a double bar on top (e.g., $\bar{\bar{x}}$). A circumflex denotes quantities that have been normalized (e.g., $\hat{x} \equiv x/x_{\mathrm{normto}}$). Differential responses are described by Δ. Partial differentiation with respect to the variable x is denoted by ∂_x. The imaginary unit is written as $\hat{\imath}$. The real and imaginary parts of a variable x are denoted $\mathfrak{Re}(x)$ and $\mathfrak{Im}(x)$, respectively.

Acronyms

ACS	Absorption cross section
CD	Circular dichroism
CPL	Circularly polarized light
DLW	Direct laser writing
DNA	Desoxyribonucleic acid
EBL	Electron-beam lithography
ECS	Extinction cross section
GLAD	Glancing angle deposition
IR	Infrared
LCP	Left-handed circularly polarized light
LPL	Linearly polarized light
NIR	Near-infrared
OC	Optical chirality
ORD	Optical rotatory dispersion
PEC	Perfect electric conductor
PMMA	Poly(methyl methacrylate)
RCP	Right-handed circularly polarized light
SRR	Split-ring resonator
STED	Stimulated emission depletion
UV	Ultraviolet
VCD	Vibrational circular dichroism