Dynamical Properties in Nanostructured and Low-Dimensional Materials

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To my wife Sandra, for her love and also for her patience during the writing of this book.

Contents

Preface

The last few years have seen dramatic advances in the growth, fabrication and characterization of low-dimensional materials, such as graphene on the one hand, and a wide variety of nanostructures on the other, such as those formed from ultrathin films, wires, disks and other 'dots'. The elements of the nanostructures may be formed either singly or in spatial arrays that can be periodic or otherwise (in one dimension or more) and may involve more than one type of material. Most studies of these artificially engineered materials have been driven by their potential for device applications that involve smaller and smaller physical dimensions and novel utilization of the nanostructuring. In particular, the dynamical properties of these materials are of fundamental interest for devices that involve high-frequency operation and/or switching.

Consequently the different waves or excitations (vibrational, magnetic, optical, electronic and so on) need to be understood from the perspective of how their properties are modified in finite structures (especially on the nanometre to micrometre length scales) due to the presence of surfaces and interfaces. Recently the patterning of nanoelements, into periodic and other arrays, has become a focus of intense activity, leading for example to photonic crystals for optical signals (and their analogues such as phononic and magnonic crystals in other contexts). Here the control of the band gaps in the excitation spectrum is a basis for a variety of applications. Furthermore, the nonlinear properties of the excitations are increasingly a topic of interest, as well as their linear dynamics, and it is often the case that nonlinear excitations may arise that have no counterpart in the linear regime. Novel materials such as single-sheet graphene and related structures have provided the accurate realization of two-dimensional structures.

The target readership of this book includes physicists, chemists, materials scientists and engineers. They may be based in universities, industry and research laboratories. The level of presentation of this book is appropriate for final-year undergraduates, graduate students and researchers. The treatment given includes both the experimental and theoretical aspects of this expanding research field, but with an emphasis on the fundamental physical principles. Readers are assumed to have a basic background knowledge of quantum mechanics, statistical physics, electromagnetism and solid-state physics. More advanced topics are introduced and explained where needed.

The author is a Professor of Physics in the Department of Physics and Astronomy at the University of Western Ontario, Canada. He is a former Chair of the department and has also served as Associate Dean of Science (Research) and as the Director of the Western Institute for Nanomaterials Science. His research expertise is in the quantum theory of condensed-matter systems and, in particular, in the dynamical properties of the excitations, such as vibrational waves (or phonons) and magnetic excitations (spin waves or magnons), in these materials. Areas of focus in his recent work have included low-dimensional structures and nanostructured materials. He is author or co-author of around three hundred research papers and

several books, including Cottam and Tilley 2004 *Introduction to Surface and Superlattice Excitations* 2nd edn (Bristol: IOP). The decade or more since that book was written has seen dramatic advances and new directions in this field, which are covered in the present publication. Notable examples are novel materials such as graphene, the development of lateral arrays of interacting elements (giving rise to emerging topics such as phononic and magnonic crystals), interest in multiferroic materials and further advances in nonlinear excitations.

I am indebted to the many friends, colleagues and collaborators who directly or indirectly have influenced this book and provided ideas.

Michael G Cottam
London, Ontario, Canada
November 2015

Abbreviations

3D, 2D, 1D, 0D	three-dimensional, two-dimensional, one-dimensional, zero-dimensional
2DEG	two-dimensional electron gas
ABC	additional boundary condition
AFMR	antiferromagnetic resonance
ARPES	angle-resolved photoemission spectroscopy
ATR	attenuated total reflection
bcc	body-centred cubic
bct	body-centred tetragonal
BEC	Bose–Einstein condensation
BG	Bleustein–Gulyaev
BLS	Brillouin light scattering
DE	Damon–Eshbach
DM	Dzyaloshinskii–Moriya
EELS	electron energy loss spectroscopy
fcc	face-centred cubic
FMR	ferromagnetic resonance
GMR	giant magnetoresistance
GNR	graphene nanoribbon
H.c.	Hermitian conjugate
HREELS	high-resolution electron energy loss spectroscopy
HP	Holstein–Primakoff (transformation)
KDP	potassium dihydrogen phosphate
LA	longitudinal acoustic
LRSP	long-range surface plasmon
MC	magnonic crystal
ML	monolayer
MQW	multi-quantum-well
n–i–p–i	(n-type)–(insulator)–(p-type)–(insulator)
NL	nonlinear
NLSE	nonlinear Schrödinger equation
OOMMF	Object Oriented MicroMagnetic Framework
PBG	photonic band gap
RKKY	Ruderman–Kittel–Kasuya–Yosida (interaction)
RPA	random-phase approximation
RS	Raman scattering
sc	simple cubic
sG	sine-Gordon
SHG	second-harmonic generation
SVA	slowly varying amplitude (approximation)
SW	spin wave
SWR	spin-wave resonance
TA	transverse acoustic
TDM	tridiagonal matrix
YIG	yttrium iron garnet

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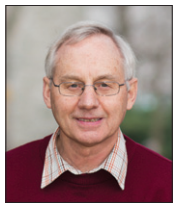
Author biography

Michael G Cottam



Michael Cottam has received his education in the UK, obtaining his Bachelor's and Master's degrees in mathematics and physics from Cambridge University and his doctorate (DPhil) in theoretical physics from Oxford University. He worked as a research scientist in semiconductor physics for the Plessey Company (UK) before becoming a faculty member at the University of Essex. In 1987 he moved to the University of Western Ontario, Canada, where he is a Professor in the Department of Physics & Astronomy. He is a former Chair of the Department and also held appointments as Associate Dean of Science (Research) and Director of the Western Institute for Nanomaterials Science. He was recently honoured by the International Astronomical Union with the renaming of a main-belt asteroid (formerly 273262) as asteroid Cottam, in recognition of his scientific work on condensed-matter systems. His research interests over the years have spanned many aspects of the linear and nonlinear dynamics of materials, particularly on the nanoscale. He is married to Sandra Fox and they have four children/stepchildren.