

Preface

A material structure assembled from a layer or cluster of atoms with size of the order of nanometers is called a nanostructure. A nanometer is about four atom diameters or 1/50,000 of a human hair. (Our fingernails are growing about a nanometer while reading this). What is so special about nanometer length scales that create so much excitement the world over? To answer this, let us consider a bulk piece of silicon having certain band gap, a feature that is a key property in electronics. If this silicon piece is shrunk to $0.1\text{ }\mu\text{m}$ (100 nm) length, the band gap will increase significantly causing silicon to emit visible light. In other words, understanding the physics of a structure at the atomic scale can help us to manipulate its properties in its bulk form. This can result in mind boggling applications that were hitherto not thought of by our research community.

There are many events such as the discovery of scanning electron microscopy that gave fillip to nanotechnology research. However, with the discovery of a new allotrope of carbon in the late 1980s and early 1990s, namely the fullerene, carbon nanotubes and graphene, a new chapter in nanotechnology research has emerged. These have become the basic building blocks for many nanodevices such as nanosensors, nano actuators, nano gyroscopes, etc. All of these devices are packaged under Nano Electro Mechanical Systems (NEMS) or Nano Opto Mechanical Systems (NOMS) devices. The key elements in these devices are the nanobeams, nanorods, nanoplates and nanoshells, respectively. This book deals with mathematical modelling of nanorods, nanobeams, nanoplates and nanoshell, which make up for the bulk of NEMS or NOMS devices.

In the mathematical modelling of physical systems, it is necessary to represent the physics of the system as accurately as possible. Understanding the physics of a material system at nanoscale level is indeed a great challenge. Performing experiments to understand its physics and formulate hypothesis is not an easy task due to extremely small sizes of the nanoscale system. Most of the behaviour has to be understood through mathematical modelling. Any modelling method should account for small-scale effects associated with these nanoscale systems. There are two different modelling methods, one based on atomistic assumptions, and the other based on continuum assumptions. In the former, we consider a group of connected atoms (typically of the order of thousands if not millions) and solve Newton's second law of motion on each atom considered. Here again, we should

make some assumptions to get the interatomic interactions. This approach is computationally prohibitive if we consider a large number of atoms in the modelling. This book mainly deals with modelling using continuum assumptions, wherein the small-scale effects are brought in through the use of non-local elasticity theory. We adopt such a modelling scheme throughout this book to study the wave propagation behaviour in nanostructures. Obviously, such modelling scheme is computationally fast and in fact all the simulations performed in this book are programmed in the general-purpose mathematical code MATLAB.

This book mainly addresses the topic of wave propagation in nanostructures. Most of the nanostructures are subjected to heavy and sometimes violent vibrations at the nanoscale, which sets up stress waves in these structures that propagate and interact with boundaries and create new waves. These waves are in the range of terahertz range and they exhibit band gap behaviour over certain frequency bands. Unlike the bulk structures, these terahertz waves have tremendous energy and their best utilization in the future generation nanodevices requires deep understanding of wave propagation in these structures.

The material developed in this book is the result of sustained research done by the senior author over the last 20 years in the area of wave propagation and the last 5 years in the area of nanostructures by both the authors. A book of this kind is an effort toward filling the need for bringing out a comprehensive textbook on wave propagation in nanostructures that will be helpful to scientists/researchers involved both in basic and applied research in the area of nanoscience and technology.

The book is written in modular form consisting of 11 chapters. [Chapters 1–4](#) present the introductory material on nanostructures, wave propagation, different modelling schemes and a basic introduction to non-local elasticity. These topics form the basis for all the chapters that follow. [Chapter 5](#) deals with nanostructure material property evaluation and small-scale effects parameter determination. [Chapters 6–11](#) deal with core wave propagation problems in different nano waveguides such as nanorods, nanobeams, nanotubes carrying fluids, coupled nano systems, multi-wall nanotubes and graphene structures. The material presented in this book can be used to develop a graduate level course in the topic of wave propagation in nanostructures. Also, this book can form as a reference material on the course of wave propagation in complex mediums. While writing this book, we have assumed that the reader has the basic engineering mechanics and graduate level mathematics background.

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