Preface

The idea of putting together this book is the result of the collective efforts of Daniel Marthaler, Luke Sweatlock, and myself while researching metamaterials and autonomous design tools within the Aerospace Research Labs at Northrop Grumman. We began looking into the area of metamaterial design using optimization methods combined with electromagnetic simulations in 2009 as an extension of our work on plasmonics and metamaterials. We quickly discovered that while there was decades worth of work on antenna and frequency selective surface design at microwave and radio frequencies, there was surprisingly little work done in the area of device design at infrared and optical frequencies using numerical methods. From a design standpoint, this also happened to be the frequency regime where materials' dispersion became most interesting. One of a few exceptions to this is the work done by Doug Werner's group at Penn State, and collaborations with Doug were an invaluable asset during our study of the field.

The design optimization methods discussed in this book are by no means a way to "hunt blindly" for solutions to design problems, and most instances of this yield extremely poor results. They are also not a replacement for a thorough understanding the underlying physics of how metamaterials respond; rather, they are a supplement to this knowledge and a valuable tool for those working in the field. In fact, the "objective functions" used to rank different candidate metamaterials' designs with respect to each other are a direct representation of the underlying physics involved in a given device design, and the success or failure of a given design optimization is critically dependent on this step. A former colleague was fond of saying "We must demand of ourselves understanding". To understand metamaterials, we must understand the underlying physics. To understand optimization, we must understand the underlying mathematics. To optimize the design of metamaterials, we must understand both.

While this text by no means encompasses all the work or methods that have been used to address the topic of optical metamaterial design, we hope that the topics covered here provide a fairly comprehensive overview of the main issues that arise when designing these structures, as well as which numerical methods are better suited for the task. This book is intended to provide a detailed enough treatment of the mathematical methods used, along with sufficient examples and additional references that senior level undergraduates or graduate students, who are new to the fields of plasmonics, metamaterials, or optimization methods, have an understanding of which approaches are best-suited for their work and how to implement these methods themselves.

The first chapter in the book is a brief overview of the major efforts within the field of metamaterials in the past and present. We touch on some of the key simulation and fabrication methods used in the field, as well as briefly review the physical mechanisms that contribute to metamaterial behavior at infrared and visible frequencies. This is done in an effort to frame the context of the book within the field as a whole.

The second chapter is an overview of the field of mathematical optimization, and describes where the methods covered in the book fit into the field as a whole. Chapters 3–5 describe the major optimization methods that are currently utilized in metamaterial design, and how differences in these methods make them more or less successful with increasing dimensionality. In Chap. 3, we discuss surrogate models that attempt to generate a maximally predictive, minimally complex model of the response of the entire design space. Chapter 4 discusses adaptive mesh optimization and examples of metamaterials designed using such an approach. Then in Chap. 5, we discuss fully stochastic methods that are based on techniques used in nature to efficiently optimize designs in very high dimensions, and numerous designs using these approaches are presented. The last two chapters of the book do not focus solely on the optimization method itself. These chapters integrate both optimization routines with novel methods for calculating and representing the shapes of the individual resonant structures within a metamaterial. These approaches are new to the field of metamaterial design; however, their applicability extends far beyond the focus of this book. This is clearly illustrated by the range of design examples that are covered throughout the last two chapters.

Finally, this book would never have been possible without a number of individuals who provided assistance, guidance, and support. A special thanks goes to Vladimir Liberman who provided thoughtful feedback regarding the individual chapters. In addition to all of the chapter authors, I would especially like to thank Harry Atwater, Erik Antonsson, Ray Bomeli, Ryan Briggs, Guy DeRose, Matthew Dicken, Bruce Esterline, James Ma, Doug Riley, Imogen Pryce, Mordechai Rothschild, Thom Schacher, Merrielle Spain, Robert Stewart, Seth Taylor, Ben Weiss, Northrop Grumman, MIT Lincoln Laboratory, and the staff at Springer.

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