Chapter 12
Active and Passive Metamaterials and Metasurfaces

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ABSTRACT

The authors of this chapter begin by discussing the fundamentals of metamaterials and metasurfaces before moving on to active and passive metamaterials. This chapter is broken up into six different sections. In the first section, an overview of metamaterials and metasurfaces is provided, and in the second half, active and passive metamaterials and metasurfaces are discussed. This is followed by an explanation of active metamaterials and metasurfaces in part three, fabrication methods for metamaterials and metasurfaces in part four, future directions and challenges in the field of metamaterials in part five, and a conclusion in part six.

I. INTRODUCTION

A. Definition of Metamaterials and Metasurfaces

To put it simply, metamaterials are man-made creations with extraordinary properties that can't be found in nature. The material's structure, rather than its chemical make-up, is responsible for these characteristics. Negative refractive index, superlensing, and invisibility cloaking are just a few of the extraordinary optical, acoustic, or electromagnetic features that can be engineered into metamaterials.2D surfaces called

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metasurfaces are organized on a scale smaller than the wavelength of light, giving them the ability to bend and refract light in novel ways. Though conceptually similar to 3D metamaterials, metasurfaces are often more thinner and easier to construct. By manipulating the phase, amplitude, and polarization of light, metasurfaces open up new possibilities in optics and photonics.

Several disciplines, such as physics, materials science, engineering, and optics, are actively investigating metamaterials and metasurfaces.

B. Brief History of Metamaterials and Metasurfaces

The idea of a material with a negative refractive index led to the development of the first metamaterials in the early 20th century. The word "metamaterial" wasn't used to describe materials having extraordinary qualities that had been produced artificially until the 1990s. Microwave interaction led to the development of the earliest metamaterials, which were arrays of tiny metallic resonators. Light, sound, and other forms of electromagnetic radiation are all susceptible to manipulation by metamaterials, which have been produced since then. Duke University scientists developed the first "invisibility cloak" in 2006 (Schurig et al., 2006) by utilizing metamaterials to deflect light around a small item, making it invisible to the naked eye. Much anticipation for the development of novel optical devices and applications based on metamaterials was sparked by this breakthrough. The first experimental demonstrations of metasurfaces just appeared in the early 2010s. Improvements in nanofabrication methods allowed scientists to build structures with exact nanometer-scale dimensions and forms, paving the way for the development of metasurfaces. Since then, lenses, holograms, and polarizers are just some of the optical devices that have been made possible with the help of metasurfaces. They have also been used in areas like thermal and acoustic engineering. The development of more precise methods for manipulating light has led to exciting new possibilities in areas like communications, sensing, and imaging.

C. Importance of Active and Passive Metamaterials and Metasurfaces

There are two distinct forms of metamaterials and metasurfaces, which are known respectively as passive and active. To alter light or other kinds of electromagnetic radiation, metamaterials and metasurfaces can be passive or active. Passive metamaterials and metasurfaces are those that do not require any external energy source. They do this by relying on the inherent structural features of the material, which modifies the way the radiation behaves. Active metamaterials and metasurfaces, on the other hand, need an external energy source in order to modify light and other

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