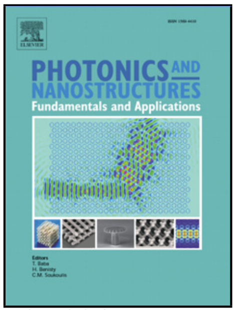

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Tunable Focusing by a Flexible Metasurface

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Abstract

An efficient reflective metasurface with elastically tunable focal length is proposed and experimentally demonstrated. The metasurface consists of electric resonators embedded in a stretchable elastic substrate which allows continuous elongation of the system. Our theory and numerical simulations predict how the focal length is controlled by means of the stretching, which we experimentally verify. By performing phase-sensitive measurements of the scattered field, we are able to differentiate the true focus, where all scattered waves are in phase, from the point of maximum amplitude. These phase measurements further enable us to characterise an axial aberration in the stretched structure, due to rays projected from distinct parts of the structure converging at different focal lengths. Additionally, we characterise the efficiency of our structure, showing that 78-95% of the incident power is reflected, depending on the degree of tuning. We also quantify the fraction of incident power which is directed into the beam waist. Our results demonstrate that metamaterials integrated with engineered elastic structures are an effective platform for functional devices.

1. Introduction

Metasurfaces represent the most promising class of metamaterials for real applications, whereby arbitrary wavefront and polarisation control can be achieved using just a single sub-wavelength layer [1, 2]. Examples of demonstrated functionality include reflection and refraction into anomalous directions [3], generation of beams with orbital angular momentum and focussing [4]. These applications require an abrupt phase change to the incident wavefront at the metasurface [5], to achieve full control over the phase of the reflected or transmitted waves. In practice, most metasurface applications require a very large range of phase values, however they can be wrapped back into the fundamental range $[0, 2\pi]$ [6]. This introduces a spatial discontinuity in parameters which becomes problematic when tuning attributes such as focal length or steering angle, or varying the operating frequency. In such cases, the phase discontinuity needs to be shifted to a different location on the surface, a process that is very challenging to implement since the resonators close to the discontinuity must undergo an extreme shift in phase response. Our approach to overcome this problem is to incorporate our metasurface within a flexible elastic structure, ensuring continuous control over the metasurface properties.

The incorporation of elastic materials with unconventional mechanical properties in the design of reconfigurable metamaterials has proven to be an appealing approach for the creation of tunable electromagnetic devices [7, 8]. The great flexibility of elastic materials in terms of fabrication allows the creation of complex structures with electromagnetic properties that can be controlled by external stimulus [9, 10]. Such control becomes more effective when electromagnetic resonators or electronic devices are embedded in specially engineered elastic materials [11, 12], where novel applications across the spectrum can be implemented by harnessing the unique geometrical conformation that the surrounding elastic medium achieves under strain [13].

This integration enables the design of optical devices based on metamaterials, such as flexible surfaces or three-dimensional materials, with tunable electromagnetic responses that depend on the spatial arrangement of the surface components [14].

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