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Making structured metals transparent for ultrabroadband electromagnetic waves and acoustic waves

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HIGHLIGHTS

- Making structured metals transparent for ultrabroadband electromagnetic waves.
- Non-resonant excitation of surface plasmons or spoof surface plasmons.
- Sonic artificially metallic structures transparent for broadband acoustic waves.

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ABSTRACT

In this review, we present our recent work on making structured metals transparent for broadband electromagnetic waves and acoustic waves via excitation of surface waves. First, we theoretically show that one-dimensional metallic gratings can become transparent and completely antireflective for extremely broadband electromagnetic waves by relying on surface plasmons or spoof surface plasmons. Second, we experimentally demonstrate that metallic gratings with narrow slits are highly transparent for broadband terahertz waves at oblique incidence and high transmission efficiency is insensitive to the metal thickness. Further, we significantly develop oblique metal gratings transparent for broadband electromagnetic waves (including optical waves and terahertz ones) under normal incidence. In the third, we find the principles of broadband transparency for structured metals can be extended from one-dimensional metallic gratings to

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two-dimensional cases. Moreover, similar phenomena are found in sonic artificially metallic structures, which present the transparency for broadband acoustic waves. These investigations provide guidelines to develop many novel materials and devices, such as transparent conducting panels, antireflective solar cells, and other broadband metamaterials and stealth technologies.

1. Introduction

Making metals transparent for white light, which could achieve various fascinating applications in optoelectronics, has been expected for a long period. Bulk metals are naturally opaque to light due to the large index mismatch between metals and dielectrics. In recent years, by introducing artificial structures, it becomes possible to achieve transparent metals beyond their natural characteristics. For example, it has been found that surface plasmons (SPs) [1] or spoof surface plasmons (SSPs) [2] on the surface of structured metal can lead to extraordinary optical transmission [3–7]. Moreover, continuous (apertureless) metal films can become transparent due to the scattering cancellation mechanism [8,9]. Besides, electromagnetically induced transparency [10–12] can be realized by introducing metamaterials [13–25], which are constructed by metallic micro- and nano-structures. However, due to the underlying resonance mechanisms, all of these transparency phenomena occur only within very narrow frequency band, and the transmission efficiency is usually low for thick materials.

Fortunately, in 2010 we theoretically found for the first time [26] and later experimentally demonstrated [27] that metallic gratings can be made transparent for extremely broadband electromagnetic waves under oblique incidence. This unusual phenomenon can be understood either by our non-resonant excitation mechanism of SPs or SSPs on microscopic level [26–29] or by the anomalous impedance-matching mechanism from Alú's group [30–32]. For technological applications the oblique incidence geometry is inconvenient. To solve this problem, we have developed oblique metal gratings to achieve broadband transparence at normal incidence [26,27,33]. Besides, adiabatically tapered slits have been proposed to widen the angular range of incidence [34]. These structured metal microstructures have presented significant transparency and can be applied for conducting panels [9,35,36], white-beam polarizers [37], anti-reflective solar cells [28,38], etc.

Metallic gratings can also become completely transparent for acoustic waves [39,40]. Since acoustic waves are longitudinal waves without polarization, we may achieve white-beam full transmission and antireflection. This may open up a new field for various novel applications of acoustic gratings, including extraordinary acoustic transmission (EAT) [41], sub-wavelength sonic imaging and screening [42,43], grating interferometry, antireflection cloaking, Talbot effect-based phase contrast imaging [44], crack detection, and various other acoustic device applications.

In this review, we present our recent work on making structured metals transparent for broadband electromagnetic waves and acoustic waves via excitation of surface waves. We theoretically and experimentally show that one-dimensional (1D) and two-dimensional (2D) metallic gratings can become transparent and completely antireflective for extremely broadband electromagnetic waves by relying on surface plasmons or spoof surface plasmons. Similar phenomena are found in sonic artificially metallic structures, which present broadband transparency for acoustic waves. And a brief perspective on future work is also given. The investigations provide guidelines to develop novel broadband electromagnetic and sonic materials and devices.

2. Making one-dimensional metallic grating transparent for ultrabroadband electromagnetic waves

In this section, we show that one-dimensional metallic gratings can become transparent and completely antireflective for extremely broadband electromagnetic waves under oblique incidence