Tunable terahertz metamaterial based on a dielectric cube array with disturbed Mie resonance

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Abstract

Tunable metamaterial operating in terahertz (THz) frequency range based on dielectric cubic particles with deposited conducting resonant strips was investigated. The frequency of the Mie resonances depends on the electric length of the strip. The simulated structure shows tunability over 20 GHz with -30 dB on/off ratio. This method of control can be applied for a design of tunable metamaterial based on various dielectric resonant inclusions.

1. Introduction

THz radiation can be used for nondestructive medical scanning, security screening, quality control, atmospheric investigation, space research, etc. [1, 2]. Artificially manufactured structures, known as metamaterials, allow obtaining desired electromagnetic properties in any frequency region. Metamaterials operating in THz frequency range have been proposed in [3]. Controllable devices such as tunable filters, switches (modulators) or phase shifters are required in order to control spectrum, power, and directivity of THz radiation. In this work we suggest and analyze tunable metamaterials based on resonant dielectric inclusions.

2. Metamaterial based on dielectric resonators

There is a number of structures with negative values of dielectric permittivity and magnetic permeability. The most popular are structures based on an array of split-ring resonators, dielectric resonators, and wire medium. In our design, dielectric resonators have been chosen as constitutive particles of the metamaterial with negative effective parameters because both negative magnetic permeability and negative dielectric permittivity can be provided by magnetic and electric resonances correspondingly [4–5]. High permittivity dielectric spheres, cubes or rods can be arranged to provide negative effective electromagnetic parameters. A design of tunable THz metamaterial based on cubic resonator array with original method of control is proposed.

3. Tunability provided by a metal strip deposited on the dielectric cube face

The dielectric cube, with a conducting resonant strip deposited on one face of the cube, is shown in Fig. 1: a). Characteristics of the material with cube array are changed by the control of the electrical

ISBN 978-952-67611-2-1

length of the strip. This dielectric cube made from a dielectric with a high dielectric permittivity has appropriate dimensions providing an excitation of the first Mie resonance in THz frequency range. The incident wave is perpendicular to the front cube face. The direction of the electric component of the EM wave is parallel to the metal strip. For a simulation of the resonant response of the dielectric cube the following dimensions of the structure have been used: the cube edge is a = 0.22 mm and the width of the metal strip is w = 0.04 mm. The permittivity of the cube dielectric material is $\varepsilon_c = 50$.

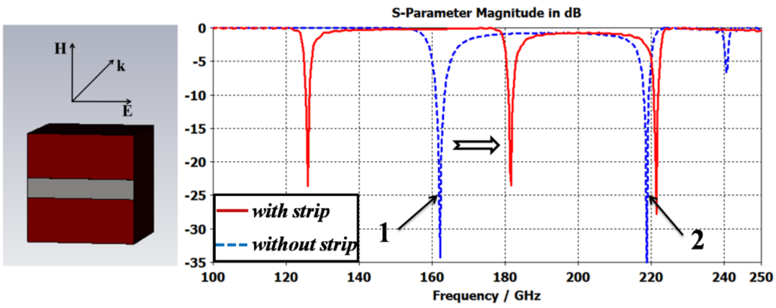

Fig. 1: a) A single dielectric cube with a metal strip b) The transmission coefficient S_{21} spectrum for the single dielectric cube with the metal strip

The transmission coefficient S_{21} for the single dielectric cube and the dielectric cube with the metal strip is presented in Fig. 1: b). The resonances 1 and 2 correspond to the first Mie (magnetic) and the second Mie (electric) resonances of the cube respectively. The frequency of the magnetic resonance is blue-shifted by adding the metal strip. And the frequency of the electric resonance is only slightly influenced by the presence of the metallic strip. A major difference from the cube without the strip is an additional resonance at the frequency f = 125 GHz. It corresponds to the electric resonance of the metal strip. Effect of shifting the resonances can be explained by the analysis of the distribution of the magnetic and electric field components near the magnetic resonance of the dielectric cube (Fig. 2).

Fig. 2: Distribution of the magnetic (a) and electric (b) field components in case of magnetic resonance (first Mie resonance) of the dielectric cube.

The field disturbance related to the strip influence on the field distribution is evidently strong for the magnetic resonance. This effect can be used for controlling the resonant frequency of the magnetic resonance. The magnetic resonance strongly depends on the electric length of the metal strip. The transmission coefficient S_{21} for different values of the electric length of the metal strip c is presented in Fig. 3.

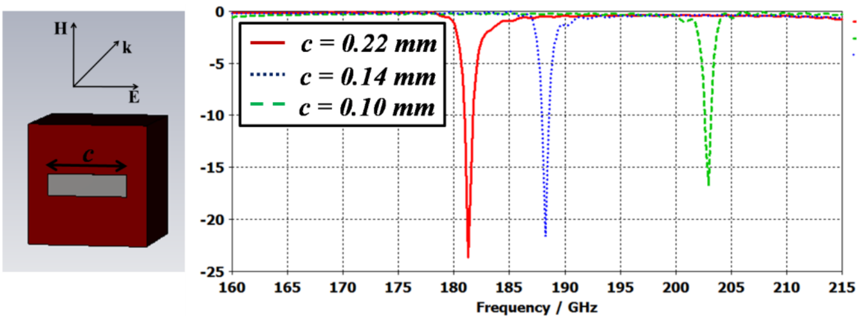

Fig. 3: Influence of the electric length of the metal strip on the transmission coefficient S_{21}.

The distribution of the magnetic and electric fields inside the cube can be changed by changing the shape of the metal strips. Thus we can control the characteristics of the material based on the dielectric cubes. For example the structure presented in Fig. 4: a) allows controlling not only the frequency of the magnetic resonance but also the frequency of the electric resonance (Fig. 4: b)). The resultant spectra shift shows over 20 GHz in 0.1~0.3 THz range.

The electric length of the strip can be changed by different methods. The first one is creating an active region in the gap of the metal strip with tunable conductivity. The maximum of the surface current is observed at the center of the strip. This region can be made of photosensitive semiconductor material. The semiconductor conductivity is changed under optical exposure. Increasing conductivity of the gap is followed by appearance of the short-circuiting bridge in the gap.

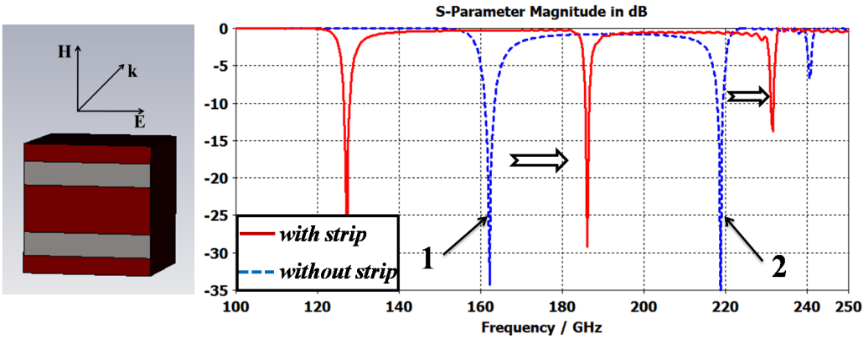

Fig. 4: a) A single dielectric cube with two metal strips b) The transmission coefficient S_{21} spectrum for the single dielectric cube with two metal strips.

The second method is based on a variation of the gap capacitance. In this case, the resonant frequency of the strip can be controlled by applying the voltage to the MEMS structure with a movable cantilever, which is included into the gap.

4. Conclusion

Tunable metamaterials based on dielectric cubic resonator with conducting strips placed on a face of the cube operating in THz frequency region have been investigated. The original method of tunability based on the field redistribution inside the dielectric resonators is proposed. This effect is obtained due to the disturbance of the Mie resonances by the conducting strip. The method of control can be provided by the change of conductivity or capacitance of the gap in the center of the strip. The method provides a fast control of the effective electromagnetic parameters of the negative-index metamaterial.

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ISBN 978-952-67611-2-1