Demonstration of Negative-Index Metasurface Composed of Concentric Copper-Dielectric Spheres

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Metameterials exhibiting DNG using spherical resonators have lately attracted much attention because of their almost isotropic and low-loss properties, makes them good candidates for various applications such as lenses of sub-wavelength resolution (superlenses). There are number of structures comprising of spherical resonators, but all of them are relatively hard to implement. For example, spheres of magnetodielectric materials are practically unrealizable while structures with two sub lattices of different-sizes and very-high permittivity dielectric spheres, or structures consisting of two or more concentric high-permittivity dielectric spheres exhibit low loss because they are made of non-magnetic materials, are complex and difficult to manufacture. This is probably the reason that some good theoretical analyses and simulations of metamaterials formed with spherical elements have been published, but to the best knowledge of this author, there were no attempts to manufacture and demonstrate this technology. Thus it would be beneficial to fabricate prototype of these metamaterial structures to confirm predicted negative-index behavior and low attenuation.

In this work we analyzed, fabricated and measured an 8-element simulator, emulating an infinite metasurface of spherical array elements. Each element consists of spherical copper-core and high-permittivity concentric dielectric shell. We pick the dimensions and materials the same as in (E.F. Kuester at al. Progress In Electromagnetics Research B, Vol. 33, 175-202, 2011) to compare the results in frequency range 2-4 GHz. The cross-section of the waveguide simulator is schematically shown in Fig. 1. The element spacing d_x=12.481mm while the rectangular waveguide with TE_{10} dominant mode has the dimensions $a=8d_x$, $b=d_x$. The spherical element has the following dimensions/materials; Copper-core: a_1=2.9mm, $\sigma=5.7\ 10^7$ S/m, $\varepsilon_{r1}=1+j\sigma/\omega\varepsilon_0$, $\mu_{r1}=1$, $\varepsilon_0=8.854\ 10^{-12}$F/m; Dielectric shell (TiO2): a_2=6.2mm, $\varepsilon_{r2}=100(1+j0.001)$, $\mu_{r2}=1$. This simulator emulates the reflection (S11) and transmission (S21) parameters for plane wave incident on an infinite metasurface at an angle of $\theta_i=33.02^0$. Fig. 2 compares magnitudes of S-parameters obtained from unit cell simulation and "waveguide simulator" simulation using HFSS code. Excellent agreement is evident which indicates that the waveguide simulator indeed emulates an infinite metasurface case. During the presentation measured data for S_{11} and S_{21} will be presented, and consequently effective constitutive parameters exhibiting DNG properties will be extracted. Other relevant properties, such as fabrication processes, low-loss in DNG region, bandwidth, and angular dependence of metasurfaces composed of concentric copper-dielectric spheres will be also discussed.

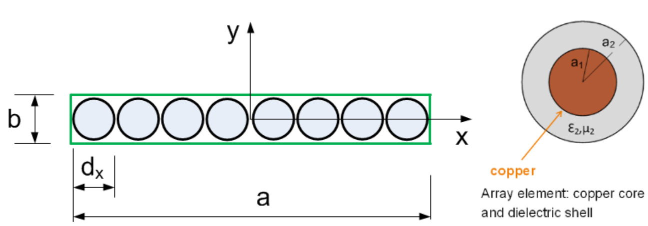

Fig. 1 Waveguide Simulator and the spherical element

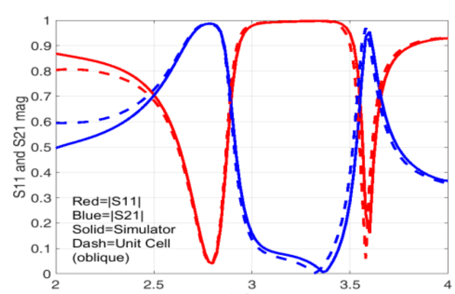

Fig. 2 S-parameters for unit cell and simulator