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Spherical and cylindrical particle resonator as a cloak system

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Abstract. The concept of dielectric spherical or cylindrical particle in resonant mode as a cloak system is offered. In fundamental modes (modes with the smallest volume correspond to $|m| = 1$, and $s = 1$) the field is concentrated mostly in the equatorial plane and at the surface of the sphere. Thus under resonance modes, such perturbation due to cuboid particle inserted in the spherical or cylindrical particle has almost no effect on the field forming resonance regardless of the value of internal particle material (defect) as long as this material does not cover the region where resonance takes place.

1. Introduction

As it well known, resonant phenomena in cavities, be they acoustic, optical, or otherwise, are frequently dependent on the precise geometric properties, such as size, shape, and composition, of the supporting structure. First explained by Lord Rayleigh [1, 2], whispering gallery modes (WGM) comprise a traveling pressure wave guided around a closed concave surface, such as the whispering gallery in St. Paul's Cathedral [3]. From a geometric optics approximation, such bound modes are guided by means of repeated reflections, which, neglecting absorption, scattering, and material dispersion, continue ad infinitum. This fact has motivated us to consider a spherical particle resonator as a cloak system.

It could be noted that the single subwavelength defect-induced backscattering in WGM resonator was investigated in [4, 5, 6] and was experimentally confirmed in [7]. In [8] a connection between the interaction of WGMs with a single subwavelength defect and the formation of the spectral doublets was directly confirmed.

Today, the two most developed cloaking techniques are: cloaking based on the wave flow method and cloaking based on scattering cancellation [9]. In the first method the object is placed in a shell which causes electromagnetic fields to bend around the object and to recover their wavefront and intensity distribution afterwards. The operation of such a shell does not depend on the properties of the hidden object, because in this case electromagnetic waves do not interact with the object.

2. Modeling

Let's briefly consider the interaction of electromagnetic field with cylindrical dielectric particle in resonant mode. An infinite long transparent dielectric square section cuboid embedded in a infinite long transparent dielectric cylinder is illuminated by a monochromatic linear polarized plane wave with an incident wave vector parallel to the Z axis. Its polarization direction is parallel to the axis of the cylinder.

We simulated this combined structure using Finite Element Method (FEM) software Comsol Multiphysics. Perfectly matched layers (PML) bound the simulation space at the all sides. At the cylindrical's shadow side, additional space with the width 2λ is added to visualize and study the resulting modes. We used a free tetrahedral mesh with maximum element size $\lambda/5$ for the free-space regions, and $\lambda/5/1.8$ for the particle. Additionally, we used a free triangular mesh with maximum element size $\lambda/20$



for the z -plane near the shadow surface of cylinder (sphere) and an even finer mesh is required for obtaining the field's spatial structures.

The simulated field magnitudes are shown in Figure 1 for cylinder diameter of 6.6234λ and refractive index of $n=1.75$. In the Figure 1a the field distribution inside and outside the homogeneous cylinder are shown. In the Figure 2b the field distribution inside and outside the homogeneous cylinder the case when a cuboid dielectric particle with dimensions of $2.41\lambda \times 2.41\lambda$ and with a refractive index of $n_2 = 1.9$ placed at the center of the cylinder is plot. As it can be seen the effect of the cuboid on the scattered field from the cylinder is clearly observed; and the resonance behavior remains unchanged. In fundamental modes (modes with the smallest volume correspond to $|m| = 1$, and $s = 1$) the field is concentrated mostly in the equatorial plane and at the surface of the sphere. Thus under resonance modes, such perturbation due to cuboid has almost no effect on the field forming resonance regardless of the value of internal particle material (defect) as long as this material does not cover the region where resonance takes place.

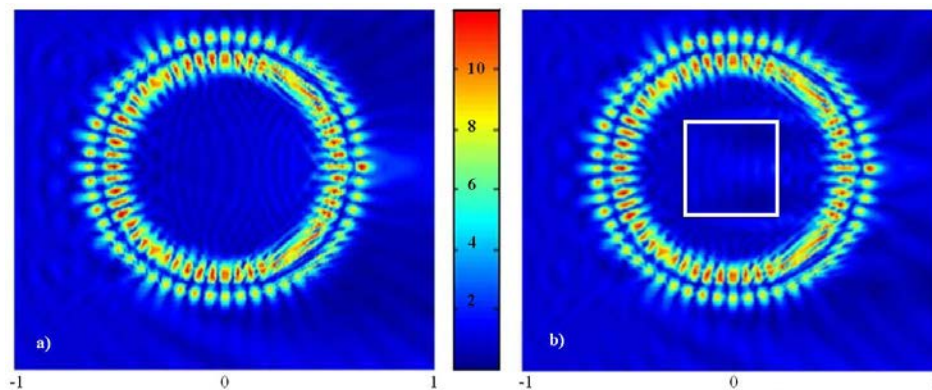


Figure 1. The simulated field magnitudes for dielectric cylinder in resonance mode.

The correspondent field magnitudes to the cases shown in Figure 1 along the cylinder diameter are shown in the Figure 2.

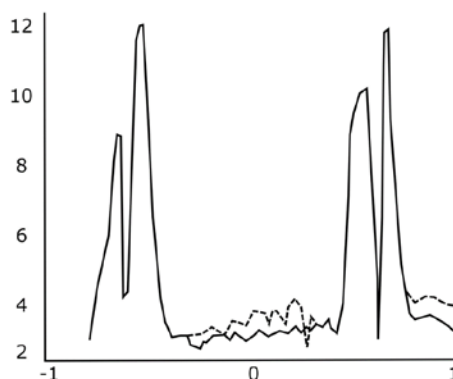


Figure 2. Magnitude of the total field along the diameter of the cylindrical particle: solid line corresponds to the homogeneous cylinder and the dashed line corresponds to the case when a cuboid dielectric particle placed at the center of the cylinder.

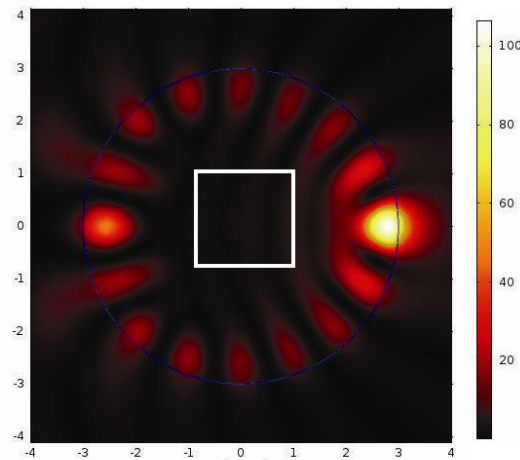


Figure 3. The simulated field magnitudes for dielectric sphere in resonance mode.

The same effect was observed for spherical particle shown in the Figure 3. In other words, if the above conditions are met, the cubic particle will not be visible when analyzing the external field of the spherical or cylindrical dielectric particle resonator.

Additional simulations shown that in non-resonant modes if we placed cuboid particle near the shadow surface inside of cylindrical (spherical) particle a photonic jet [10] focused outside the cuboid with the beam waist (FWHM) about two times smaller than that generated by the homogeneous dielectric cylinder. This effect is analogous to the effect of the photonic jet formation on the basis of a cubic particle irradiated by a focused beam [11-12].

Example of such beam compressed system concept, based on dielectric self-similar cuboids, was described in [11]. Initial wave beam is focused and transported by dielectric cubic particles with the size, magnified by M times (this can be a conventional lens system or a single lens). A mesosize dielectric cube with minimal optimal sizes, is placed in the focus of this system. Then, the initial wave beam is focused into a subwavelength region with a transverse dimension less than half a wavelength.

3. Conclusion

So, the capability of the flat reflection array to focus a monochromatic radiation at a certain point were studied. The element of the array based on waveguide with a controlled reflection coefficient was developed. The controlled phase shift is 180° . The array model based on waveguide elements was simulated in CST Microwave Studio. These simulations proved the monochromatic radiation focusing with the array made up of waveguide elements. Experimental studies of a reflective array consisting of 100 waveguide elements confirmed the focusing properties of such a array. A hardware and software complex to control the array is being currently developed. The proposed structure of the reflection array provides the high-rate focusing at a certain point.

Acknowledgments

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