Structured Surface on Subwavelength Controllable Surface Plasmon

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Introduction

The demand for broadband and thin layer radar absorbers for use in future defence systems has been a great challenge. Although the existing technology has already achieved low RCS, a step improvement in the performance will be needed for future systems.

The current techniques to reduce RCS are mainly based on shaping the surface, absorbing the incident wave and scattering. By properly designing the shape of a surface, one can reduce the reflection significantly, hence very low monostatic RCS. However, this technique can't reduce bistatic RCS, which makes the object easily detectable for more sophisticated radar networks. While radar absorbers/scatters can well be implemented on ground/sea objects, broadband and thin layer absorbers/scatters on flying objects still remain very challenging.

There has been a great interest on cloaking an object, or in other word, making an object invisible. There are basically two approaches to cloak an object: coordinate transformation and cancellation of scattering fields of the target. While the former approach might work on a reasonably wide bandwidth, at least, in theory, it is still a distance away from practical applications. The latter works based on the idea that the field generated by an object can be decomposed into spatial harmonics. The lowest order spatial harmonic of the target is then cancelled out by that of the cloak. However this approach can only be applied to sub-wavelength targets.

Recently, it has been proved, both theoretically and experimentally, that it is possible to control the interaction between incident electromagnetic wave and structured metal surface to give rise to so called spoof Surface Plasmon Polaritons (spoof SPPs) [1]. Unlike classic SPPs on unstructured metal surface, spoof SPP dispersion and spatial confinement of the surface bound modes can be engineered at will. This opens a new avenue for confining and manipulating electromagnetic wave at shallow surface by creating spoof surface plasmonic modes with desired dispersion through structure design. Since the spoof surface plasmonic modes can be induced as long as the structured surface with subwavelength unit cells and exist as evanescent waves at air-metal interface, it can be envisaged that such structured surface can be very thin and operate at very wide bandwidth.

Plasmonic Cloaks

Cloaking by cancellation of target polarization using plasmonic metamaterials was first investigated theoretically by Alu and Engheta [2-3], where a mathematical model of such a cloak was presented. Later the same authors extended the concept to collection of particles [4]. Cloaking by simply having a cloaking shell with polarisation equal and opposite to the target is easy to understand. The electric and magnetic fields of wave scattered by an object can be expanded in term of Bessel functions. If an object is small compared to the wavelength, then, on the boundary of the object, regardless of the exact geometrical shape, the higher order terms of the Bessel function will be much smaller then the first order terms, and can thus be neglected. The first order terms then represent electric and magnetic dipoles. Therefore it can be claimed that electric and magnetic fields generated by subwavelength objects are similar regardless of there exact geometrical shape, with difference only in the strength of electric and magnetic dipole, which depends mainly on the dielectric properties of the object and surrounding material.

RCS of various targets enclosed in plasmonic shell was numerically evaluated in our work and results were then presented in [5]. Fig. 1 shows the plasmonic cloak with a cube target.

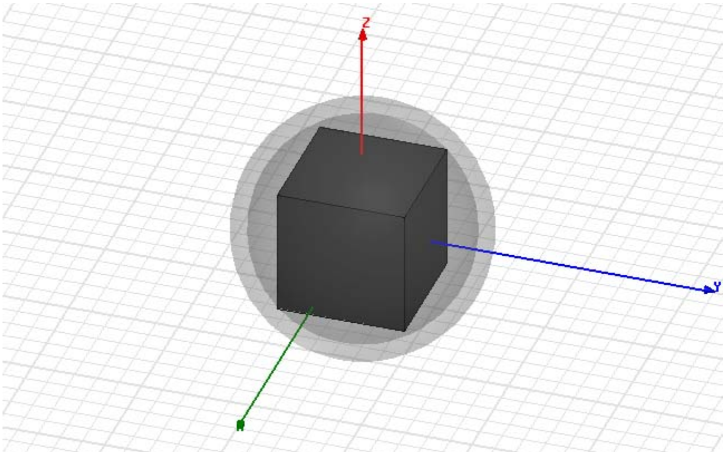
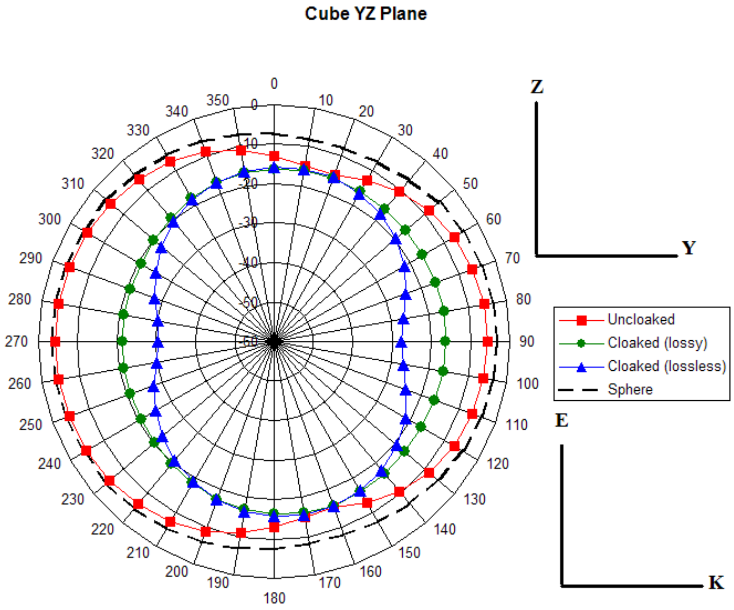
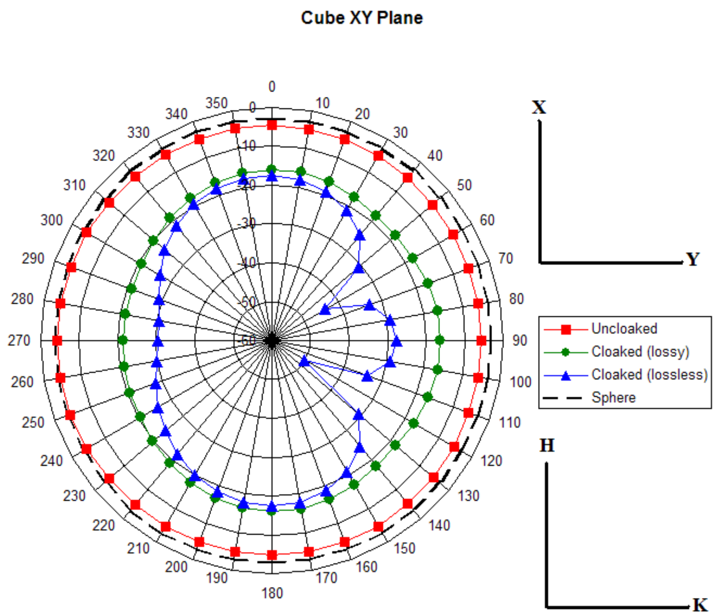


Fig.1. Plasmonic cloak with a cube target (outer radius: 57.5 mm, inner radius: 50 mm, i.e., 0.2λ at 1.2 GHz, $\varepsilon_{r,shell}$: 0.1 and $\mu_{r,shell}$: 5.1. The cube has side length of 57.75 mm).

Fig. 2 illustrates that the monostatic RCS (normalized to the square of wavelength) is -4.4 dB without cloaking, -30.7 dB and -21.5 dB with lossless and high loss plasmonic shells, respectively. It can be seen that the monostatic RCS with lossless plasmonic shell is 26 dB lower than that without cloaking, whereas for high loss case, reduction is 17dB. The simulated results are close to that reported in [4] for metallic sphere. It is evident that significant cloaking has been achieved for the metallic cube. It also becomes clear that the effect of dielectric and magnetic losses of the plasmonic shell is to degrade the RCS. The maximum value of Bistatic RCS (normalized to square of wavelength) for uncloaked and cloaked (lossy cloak) case is -4.4dB and -16dB respectively, meaning a reduction of 11.6 dB in maximum Bistatic RCS even in the presence of losses.



(a)



(b)

Fig. 2. Bistatic RCS ,dB(σ/λ^2),cube (cloak, δe=0.15, δm=0.1), (a) E plane (b) H plane.

Plasmonic Surface Mode Wave Propagation

Other area of interest in plasmonic structures is texture metallic surface. Usually such structure consists of apertures drilled into a metal surface. These holes act as metallic waveguides. A waveguide's effective permittivity is negative below cut off frequency. An array of waveguides would therefore support surface plasmonic modes below the cut off frequency of the apertures [6-7].

Several variations of metallic hole array have been investigated recently. They include; rectangular, circular, and elliptical aperture arrays; rectangular, and circular coaxial hole arrays; Sierpinski array of apertures, and eccentric annular aperture arrays.

Plasmonic mode have value k imaginary along direction normal to the plane of propagation, hence an incoming wave cannot be directly coupled to such as surface. Coupling is usually done using evanescent wave obtained through total internal reflection inside a prism. Other option is to use a grating, and couple higher order Floquent mode to the plasmonic mode.

In most of the cases there will be none zero loss in the plasmonic waveguide, which result in absorption of energy from the evanescent field. When a plasmonic structure is coupled to an evanescent field generated by total internal reflection, excitation of a plasmonic mode can be detected from dip in reflection due to absorption [7].

Plasmonic waveguides have several interesting applications. Most useful features of a plasmonic mode are sub diffraction limit confinement and extreme enhancement of electromagnetic field, [8, 9]. Plasmonic waveguides have found applications in enhancement of Raman spectroscopy [9, 10]. The reason is that normally Raman scattering signal is quite weak. Plasmonic modes enhances field in the vicinity of the sample, amplifying the radiation emitted by the sample.

Other important areas of application for plasmonic waveguides are high speed inter connects [11], and subwavelength lithography [12]. In case of lithography, the main obstacle is the lower limit imposed on the feature size due to diffraction limit. Similar problem is encountered in fabricating closely placed optical interconnect, i.e. a minimum limit on beam diameter, making it impossible to place two optical waveguides very close to each other. Plasmonic structures overcome above mentioned problems as they can focus electromagnetic fields below the diffraction limit.

Below is an example of a plasmonic surface, similar to the one reported in [13]. Structure is excited by an evanescent wave. Structure was analyzed in HFSS, using periodic boundary conditions and Floquent ports. Structure was assumed to be immersed in a medium with permittivity of 2.5. A 0.2mm thin vacuum layer was placed on top of object to obtained evanescent wave, which is generated through total internal reflection, from a plan wave incident on high permittivity-vacuum interface at an angle of 60°. Due to coupling of evanescent wave to the structure, some of the incident power is transmitted to the other side of Sierpinski Carpet array of coaxial holes shown in Fig 3. This power was numerically evaluated by HFSS. The whole unit cell is 18mm by 18mm, large square has dimension of 6mm by 6mm, whereas the inner square inside the large square has dimension of 4.5mm by 4.5mm. Smaller squares are scaled by 1/3. Structure has thickness of 0.1mm, and is constructed from Aluminium. Apertures in the structure are filled with air. Unit cell of the Structure and power transmitted to the other side of the structure are given below.

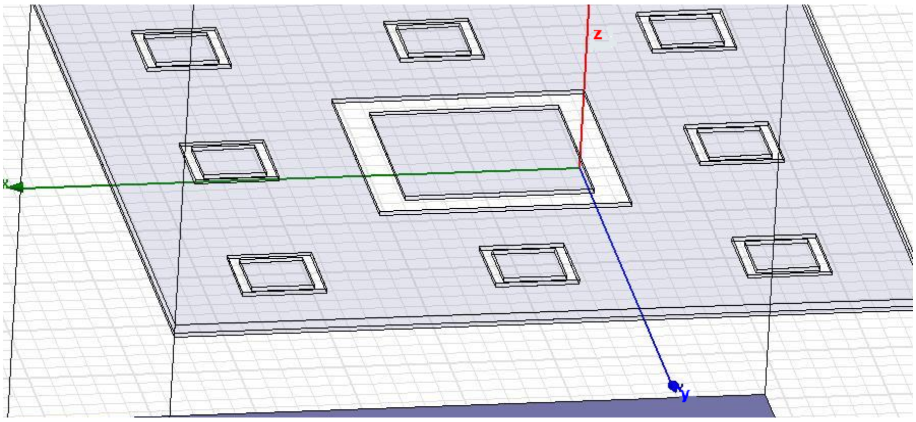


Fig. 3. Sierpinski carpet plasmonic surface

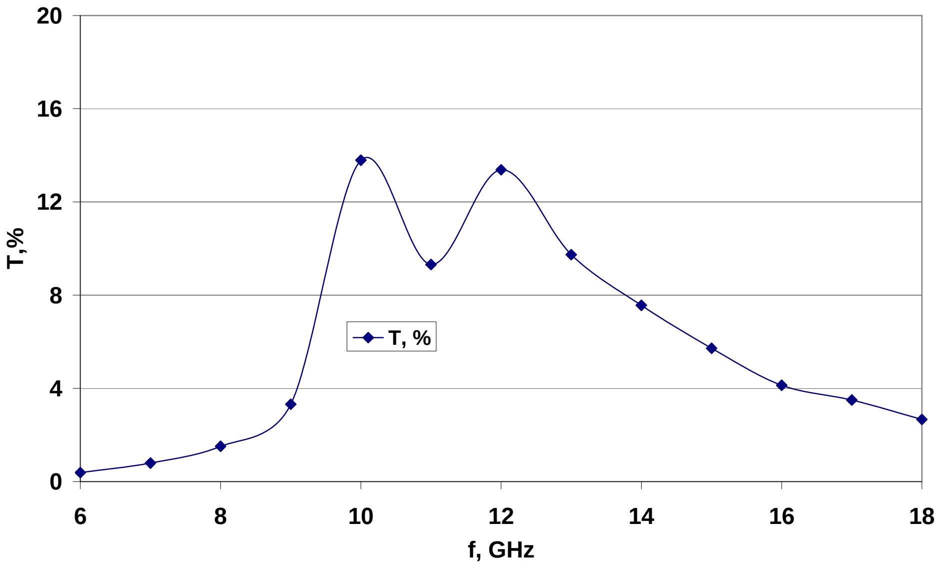


Fig. 4. Power transmitted to the other side of the structure.

The results above clearly show that significant power is transferred to the other side of the structure due to coupling to plasmonic modes.

Plasmonic Surface Radar Absorber

A radar absorber based on waveguide array plasmonic structure was investigated. The array consists of holes of 5mm by 5mm in a 1.7S/m material with a period of 8mm. Thickness of the structure is 5mm. Holes are filled with a dielectric with relative permittivity of 4. As the hole dimensions are below half wavelength, its modes inside the holes are below cut-off, and thus plasmonic. Unit cell of structure and results are shown in Fig. 5 and 6.

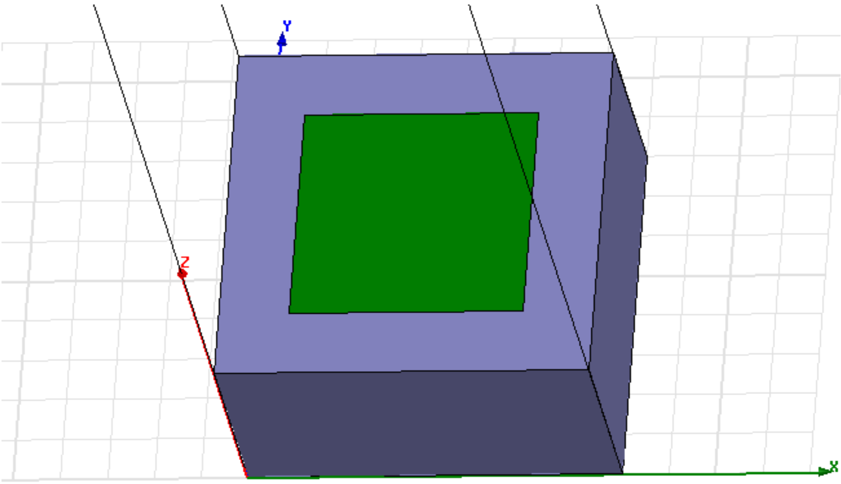


Fig. 5. Unit cell of plasmonic absorber.

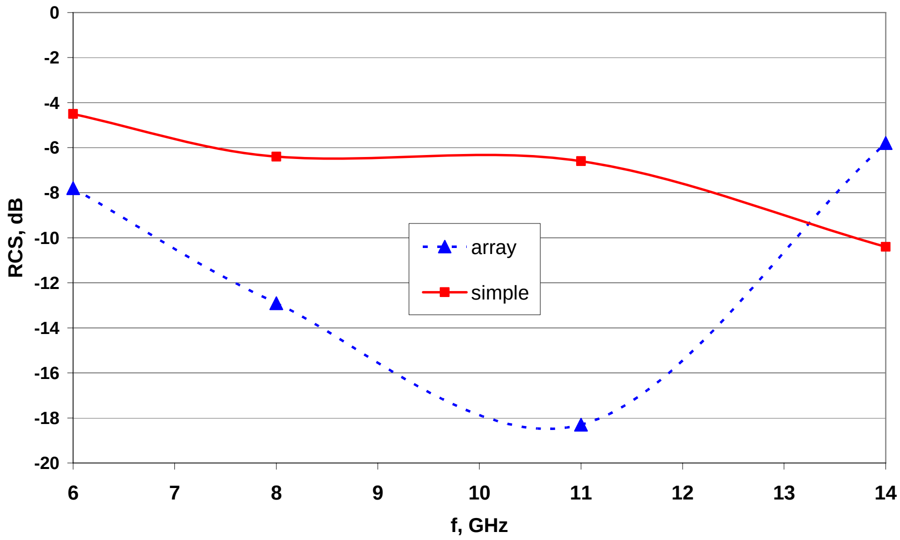


Fig. 6. RCS (normalized to that of PEC ground plan) for the array and simple layer of lossy material.

In the above results RCS of a PEC plan covered by the array is compared to that of a PEC plan covered in simple layer of lossy material with the same thickness. It can be observed that the structured plasmonic gives much better results than a simple layer of same material with the same thickness. This implies role of plasmonic modes in absorption.

Conclusion

In this paper current status of research in plasmonic structures, such as plasmoinc cloaking, plasmonic surface wave propagation and plasmonic radar absorber was briefly reviewed in addition to the work being done at University of Manchester. It can be concluded that plasmonic structures hold great promise of interesting electromagnetic applications.

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