A novel plasmonic nanofilter based on complementary H-fractal shape components

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***Abstract*- We propose a novel infrared nanofilter of localized enhanced field with multiband resonant frequencies. Compared to the resonant wavelength, the structure size is very subwavelength. We establish the effective medium theory to illustrate the light field distribution of the fractals. The loss factor is used to retrieve relative permittivity which is utilized to reproduce of reflection and transmission coefficients in the effective homogeneous plate. By bringing the inevitable metal loss to advantage, the enhanced factor of the field in the filter can reach a factor of 16 times amplification.**

I. INTRODUCTION

Metamaterials, taking advantage of its unique properties to realize the phenomena inexistent or unusual, have attracted a great number of researchers' attention for years. The investigation scopes of the metamaterials arise from the lefe-handed materials which were theoretical proposed in last century by a Russian scientist [1]. The first successful experiment to fulfill the double negative (both the permittivity and permeability are negative) material has been conducted with spilt ring resonator and a long vertical metallic line in microwave regime [2]. Following this work, many researchers moved forward along this paradigm [3, 4, and 5]. In the year of 2006, with the transformation optics [6,7] introduced by a British scientist, the interests on metamaterials were greatly enhanced and many imaginations only in science fiction came true, at least quite achievable in simulation design. The invisible cloak, illusion and carpet were designed and some of the designs were verified by experiments mainly in microwave regime. However, both double negative materials and devices based on transformation optics have encountered so many bottlenecks because of the bandwidth, losses, singularity, fabrication, and so on. There are at least one or more factors restricting the progress of metamaterials. Recently, the concept of metadevices was introduced by Professor Zheludev in Optoelectronic Research Center in UK. The agenda was transferred to focus on the reconfigurable, nonlinear and switchable devices based on metamaterials [8].

A fractal structure possesses self-similar properties and the scaling law indicates that such structure naturally exhibits multiband electromagnetic responses covering an ultra-broad frequency regime. Many interesting electromagnetic properties have been investigated in a series of fractal structures, such as Hilbert curve, Minkowski curve, Sierpinski carpet [9], and so on [10]. Among these choices of fractal geometries, H-shaped fractals offer an opportunity to construct the electric metamaterials [11], magnetic metamaterials [12] and plasmonic metamaterials [13, 14] with desirable properties, covering from the microwave to visible regime.

In this paper, we take advantage of the two amazing features of fractals, as well as the surface plasmons, to reveal the strong localized field enhancement of a quasi-3D plasmonic multiband nanocavity in the infrared region. We investigate the four-level fractal geometry perforated gold film and its complementary metallic fractal patterns, respectively.

II. SIMULATION MODELS AND DEVICE STRUCTURE

The composite is composed of a physically separated bottom gold film with perforated fractal geometry (figure 1(b)) and complementary larger size metallic fractal arrays (figure 1(c)) at the top of the structure. Just as shown in figure 1(a), the bottom layer is perforated with four-level H-shaped fractal patterns.

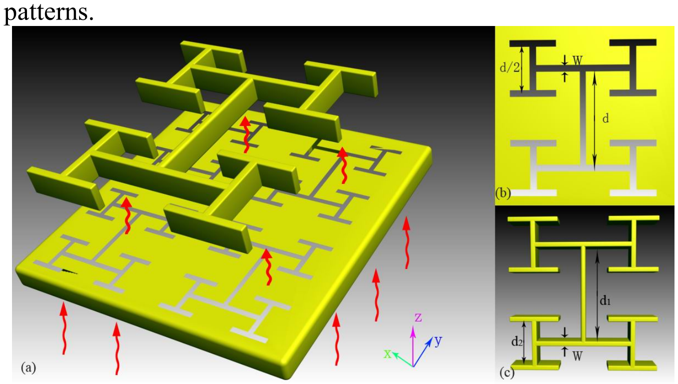

Fig. 1: (colour online) Schematic of a unit cell in a square lattice of the composite. The incident electromagnetic field illuminates on the structure from the bottom with its polarization along *x* axis. (b) The top view of the perforated metallic film cell with fractal geometry in *xy* plane. For our simulation, the center line length is *d*=300nm, *w*=30nm, and the periodicity is 600nm*600nm. (c) The top view of unit cell of fractal metallic patterns in *xy* plane. The lattice constant is 1200nm*1200nm. The first level length d_1 is 600nm and the third level d_2 is 390nm. The width of the rods is 30nm and the thickness of both the film and fractal pattern is 100nm in our calculation.

III. RESULT AND DISCUSSION

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The geometry parameters are systemically optimized and the reflectance dips are gradually moving to the ground of zero intensity. The Fig. 2 shows the reflectance spectrum as a function of key variable spacer thickness.

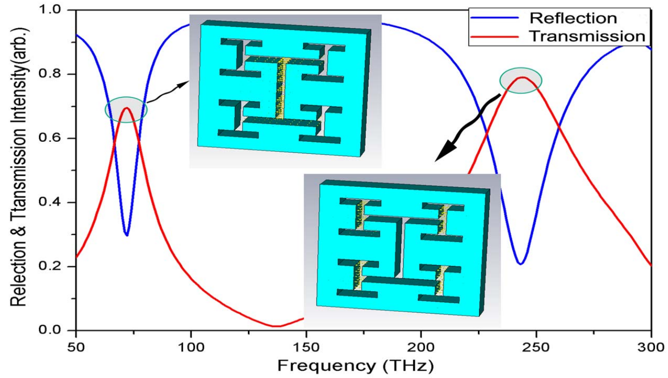

Fig. 2: (colour online) The transmission and reflection spectrum of the perforated metallic film with fractal geometry in figure 1(b). There are two transmission peaks at frequencies about 73THz and 243THz. The insets respectively show the electric field distributions at the two frequencies. Each electric field distribution corresponds to one level resonance.

It can be seen in figure 2 that most of the incident light is reflected back among the wide range of the frequencies. However, there are two narrow dips at frequencies about $f_1 = 74THz$ and $f_2 = 243THz$ in the reflection spectrum. The extraordinary high transmittance at the two frequencies indicates the peculiar passband property in the individual structure. In order to illustrate the intrinsic physical basis of narrow transmission peaks, the insets of figure 2 respectively show the electric field distributions at the two frequencies. At the frequency about 74THz, the electric field is mainly located in the first-level slit.

IV. Conclusion

Taking advantage of the H-shaped fractals, we design a novel plasmonic nanocavity, especially the multiband transmissions which are corresponding to the levels of the fractals. This will have great potential in those applications where high localized fields are required.

Acknowledgements

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