A Compact Plasmonic 4-way Wavelength Splitter for Planar Circuits

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Abstract— A compact plasmonic 4-way wavelength splitter with band-stop filters at microwave frequencies is proposed. The splitter is based on specially designed plasmonic structures and band-stop filters. The plasmonic structures are placed on the dielectric substrate and consist of two metal gratings with corrugated grooves in the inner surface, which are suitable for integration with planar circuits. The band-stop filters are constructed by composite-periodic grating structures with different groove depths, which can improve the isolations between different branches. The plasmonic 4-way splitter is investigated numerically based on full-wave simulations at microwave frequencies. Electromagnetic (EM) waves at the designed frequencies are confined and guided along different branches with good isolations.

1. INTRODUCTION

Plasmonics forms a major part of the fascinating field of nanophotonics, which explores how EM fields can be confined smaller than the wavelength. It is based on interaction processes between EM radiation and conduction electrons at metallic interfaces or in small metallic nanostructures, leading to an enhanced optical near field of sub-wavelength dimension [1]. Surface plasmon polaritons (SPPs) as one of the main ingredient of plasmonics which can propagate along the metal surfaces and can be tightly confined to sub-wavelength size beyond the diffraction limit at visible frequencies [2]. Recent researches have shown that structured metal surface drilled with arrays of sub-length holes or grooves at terahertz (THz) or microwave frequency can strongly support a kind of surface EM modes, whose behave is similar to the SPPs and names as spoof SPPs (SSPPs) [3, 4]. The dispersion relation of SSPPs is determined by the shape and dimension of the subwavelength holes or grooves, so it provides an effective way to guide and manipulated EM surface waves.

In recent years, various geometries of structured surfaces have been proposed to guide the propagation of SSPPs. In Ref. [5], a back-side slit-illumination method that incorporates a periodic array of grooves carved into the front side of a thick metal film was proposed to generate a unique propagation direction for SPPs. A THz frequency splitter based on a bidirectional subwavelength slit resonating was proposed to guide the EM waves with different frequencies propagated along the opposite directions and then a theoretical discussion of the design of bidirectional wave couplers based on plasmonic Bragg gratings in the near infrared domain was presented [6, 7]. A surface wave splitter based on metallic gratings with sub-wavelength aperture can support surface waves with different frequencies at different sides [8]. Then a metal-film bidirectional surface wave splitter which can guide light at two visible wavelengths in opposite directions was demonstrated [9]. A bidirectional surface wave splitter excited by a cylindrical wire in the microwave frequency which has two grating branches with different depths was proposed [10]. Then a multidirectional surface wave splitter was presented in Ref. [11], but the isolation at low frequencies is bad. Recently, a multidirectional frequency splitter with band-stop plasmonic filters was proposed [12], and improved the problem of bad isolation at low frequencies appeared in Ref. [11].

In this paper, we proposed a novel 4-way wavelength splitter at microwave frequencies fed by coplanar waveguide (CPW). The 4-way splitter has a compact structure and suitable for planar circuits integration. The planar band-stop filters are introduced to improve the isolation between these four branches. The simulation results based on CST Microwave Studio (CST) show good performance of the special designed 4-way wavelength splitter.

2. DESIGNS AND SIMULATIONS

The 4-way splitter is composed of four branches and each branch consists of two symmetrical metal grating structures. The structure is shown in Fig. 1(a). Compared with the structures proposed in Refs. [10–12], the proposed plasmonic structure is placed at the surface of dielectric (FR4) whose thickness d is 0.5 mm and dielectric constant is 4.9. Obviously, this structure is suitable for planar integrated circuits. At the front of each branch is band-stop filter except *branch* 4. The thickness

t of the metal is 35 μm. The groove period and groove width are p and w, where $p = 5$ mm, $w = 2$ mm and the depths of the grooves of four branches is h_1, h_2, h_3 and h_4, where $h_1 = 3$ mm, $h_2 = 5$ mm, $h_3 = 8$ mm and $h_4 = 11$ mm, respectively. The insulator between two graded metal grating structures is air and its width w_air is 2 mm. It is excited by CPW. The dispersion curves of such periodic structure can be calculated by using the eigenmode solver of CST. Fig. 1(b) shows the dispersion curves of the structures whose groove depths are 3 mm, 5 mm, 6 mm and 10 mm, respectively.

From Fig. 1(b), we can see that the EM waves at 9 GHz, 7 GHz, 5 GHz and 3 GHz can well propagate on the branches whose groove depths are 3 mm, 5 mm, 7 mm and 11 mm, respectively. But at low frequencies, the problem of bad isolation will appear as mentioned in Ref. [11]. So we designed the band-stop filters at the front of branches to apparently improve the isolation at low frequencies. For the *branch* 4, there is no need to design a filter, because the EM waves at other frequencies have been stopped and cannot propagate along this branch. The band-stop filters consist of double-periodic groove grating as shown in Fig. 2(a), the depths of shallow grooves and deep grooves is h_{f1} and h_{f2}, the period of composite structure P_f is 10 mm. The transmission spectra (S_{21}) of the band-stop filters with different h_{f1} and h_{f2} are given in Fig. 2(b). It shows that the performance of the band-stop filters can meet our design requirement.

The simulation results of the 4-way splitter are shown in Fig. 3. The two-dimension (2D) electric field distribution at the planar of $z = 1$ mm are observed. We can clearly see that the EM waves at

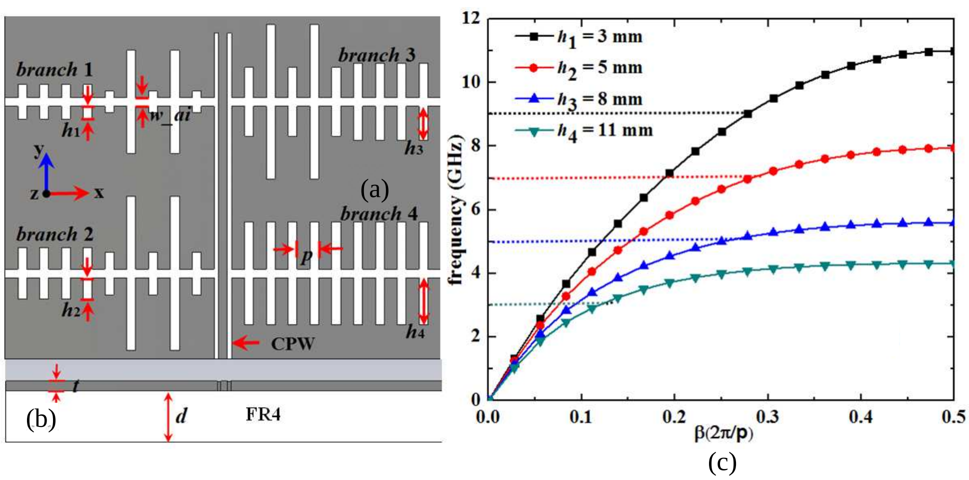

Figure 1: (a) Top view of 4-way wavelength splitter; (b) side view of the structure; (c) the dispersion curves of the four branches, corresponding to $h_1 = 3$ mm, $h_2 = 5$ mm, $h_3 = 8$ mm and $h_4 = 11$ mm, respectively.

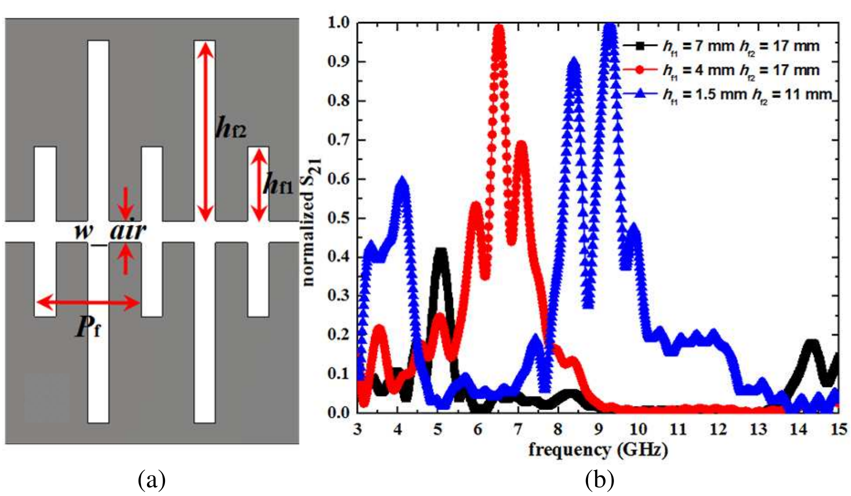

Figure 2: (a) The sketch of band-stop filter, $P_f = 10$ mm, w_air = 2 mm, h_{f1} and h_{f2} are variable; (b) transmission spectra (S_{21}) of the band-stop filters, black, red and blue lines are corresponding to $h_{f1} = 7$ mm and $h_{f2} = 17$ mm, $h_{f1} = 4$ mm and $h_{f2} = 17$ mm and $h_{f1} = 1.5$ mm and $h_{f2} = 11$ mm, respectively.

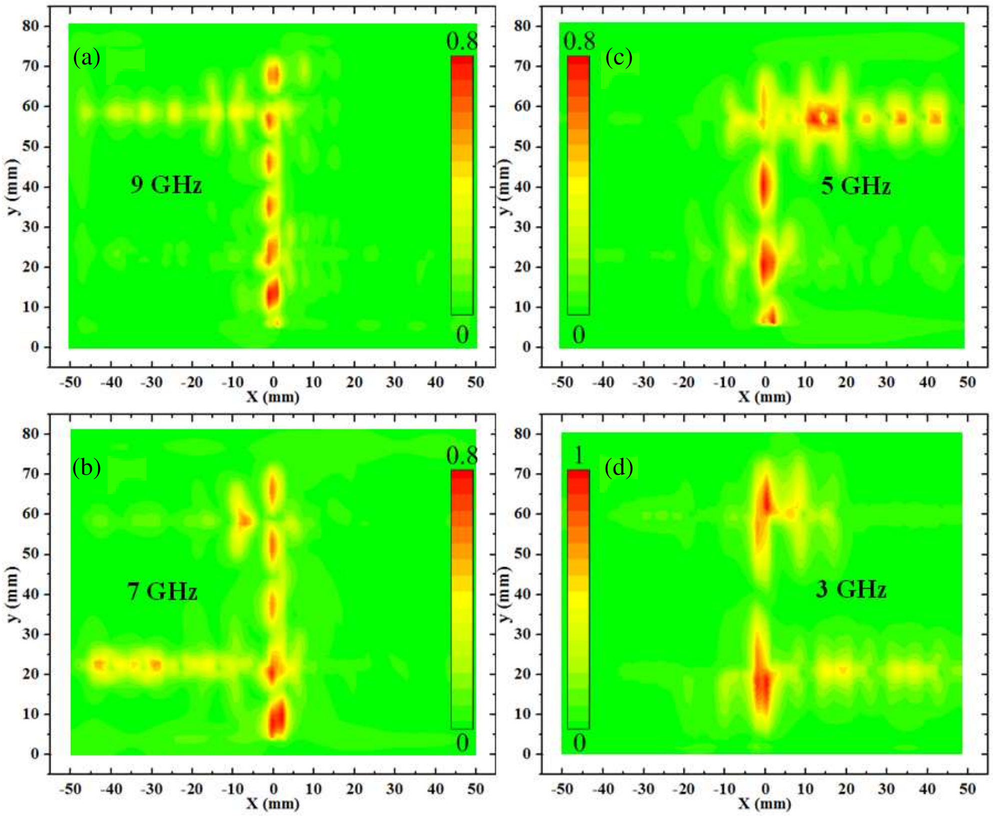

Figure 3: 2D E-field distribution of 4-way wavelength splitter; (a), (b), (c) and (d) corresponding to EM waves with the frequencies of 9 GHz, 7 GHz, 5 GHz and 3 GHz.

the frequencies of 3 GHz, 5 GHz, 7 GHz and 9 GHz are propagating along different branches with the depths of grooves of 11 mm, 8 mm, 5 mm and 3 mm, respectively. The isolation at low frequency is very well. It shows that the performance of this compact plasmonic 4-way wavelength splitter with band-stop filters is good.

3. CONCLUSION

We have proposed a compact plasmonic 4-way wavelength splitter at microwave frequency, which can make EM waves at different frequencies propagating along different branches. The introduction of band-stop filters improved the isolation between branches. The simulation results show that the performance of the designed 4-way frequency splitter is good. The whole structure can be easily manufactured by existing printed circuits board (PCB) technologies and it is suitable for the integration with planar circuits.

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