Tunable Rejections of Metamaterial Filter Based on Spoof Surface Plasmon Polaritons

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Abstract— According to the dispersion property, spoof surface plasmon polaritons (SPPs) can be supported within a low-pass propagating band. When the operating frequency rises to approach the asymptotic limit, which is also known as the surface plasma frequency, the spoof SPP modes vanish and the propagation cuts off. In this paper, we propose a method to achieve tunable rejections of spoof SPPs by producing independent absorptions. A spoof SPP waveguide consisting of corrugated microstrip line and matching convertors is introduced and electrically resonant metamaterials, the electric-field-coupled-LCs (ELCs), are employed and arranged along both sides of the waveguide. Since the electric field around the SPP waveguide excites strong and tight coupling to ELCs at resonant frequencies and their relative impedance keeps matching within a broadband, the propagating SPP modes are absorbed by such metamaterial particles and SPP filters with broad propagating band and significant rejection are achieved. Furthermore, the transmissions of the SPP filter with a series of ELCs scaled by different factors are investigated to clarify that the resonant frequency is directly controlled by the dimension of the metamaterial particles and that the coupling effect between different ELCs are weak enough to be ignored. As a result, it is convenient to control the absorptions by simply modulating the scaling factors of ELCs to construct a multiple rejection filter.Simulation results prove that the filter exhibits several significant rejections of -15 dB within a broad high-efficient propagating band. The proposed highly-efficient ultrathin planar filter is able to play an important role of filtering SPP waves in plasmonic circuits and systems.

1. INTRODUCTION

Surface plasmon polaritons (SPPs), the propagating electromagnetic waves along metal-dielectric interfaces [1], show the significant properties of high confinement and much shorter operating wavelength, which provide favorable conditions to overcome the diffraction limit [2]. Therefore, SPPs have been researched in areas of super-resolution imaging [3], electromagnetically induced transparency (EIT) [4], SPP circuits [5] and energy harvesting [6]. In 2004, Pendry et al. proposed an approach to achieve spoof SPPs by means of periodic holes [7]. Since then, a series of researches have been reported on spoof SPPs based on subwavelength holes or grooves [8–11]. Among the many Spoof SPPs studies, an ultrathin corrugated metallic strip waveguide fabricated on near zero thickness substrate is very promising [9]. Recently, a highly efficient broadband SPP waveguide was realized via the conversion from coplanar waveguide to the ultrathin corrugated metallic strip line [11].

In this work, we reported a convenient approach to control the rejections of spoof SPPs. When the electrically resonant metamaterials, the electric-field-coupled-LCs (ELCs), are introduced near the SPP waveguide, a strong coupling would be excited inside the ELCs and the propagating surface waves would be absorbed by the metamaterial particles. By manipulating the sizes of ELCs, the rejections of Spoof SPPs can be controlled freely. Such phenomenon could play an important role in plasmonic circuits and systems.

The proposed spoof SPP device, as is shown in Fig. 1, is composed of a meliorated corrugated metallic strip and an array of ELCs. Themeliorated SPP waveguide is fabricated on the basis of the design introduced in Ref. [11] and shows two constitutive improvements comparing with it. Firstly, we design the waveguide with grooves protruded out of the metallic strip line. Such design could provide a solution of miniaturization. Since the depth of grooves enlarges as the operating frequency shifts to a lower frequency, the width of the SPP waveguide introduced in Ref. [11] would be inconvenient for the measurement in the experiment. However, our meliorated waveguide possesses a relatively stationary width within a wide frequency band. Secondly, the ceiling of the grooves with deepening depths is beveled to better couple the excitation with spherical-like wave front coming out of the exponential slot lines.

According to the electric field distribution near the corrugated metallic strip, the ELCs with their equivalent capacitors of two inner metal lines parallel to the waveguide can provide a strong

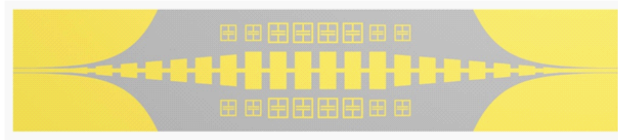

Figure 1: The schematic configuration of the DFR SPP waveguide.

resonant effect. To identify the ELCs' resonant properties and the rejections of our filters, a series of single rejection devices with different sizes of ELCs are simulated and their transmission coefficients are shown in Fig. 2. From the figure we can summarize that, by introducing such electrically resonant metamaterials, a significant rejection is obtained during the transmission and the rejecting frequencies shift along with the changes of ELCs' sizes.

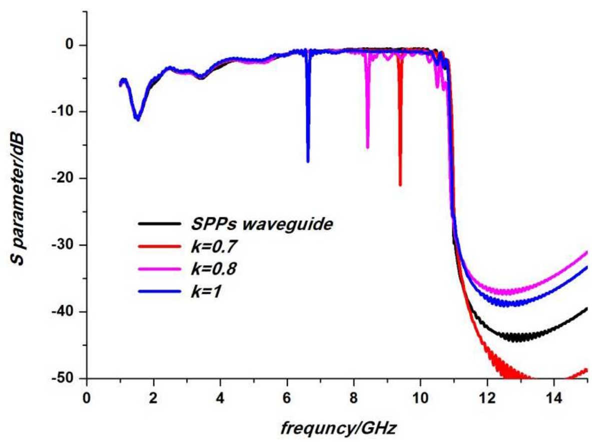

Figure 2: The transmission coefficients of the SPP waveguide with different ELC scaling factors, in which the black line stands for the spoof SPP waveguide without ELCs, while the red, pink, and blue lines represent the DFR SPP wavguides with scaling parameters $k = 0.7$, $k = 0.8$, and $k = 1$, respectively.

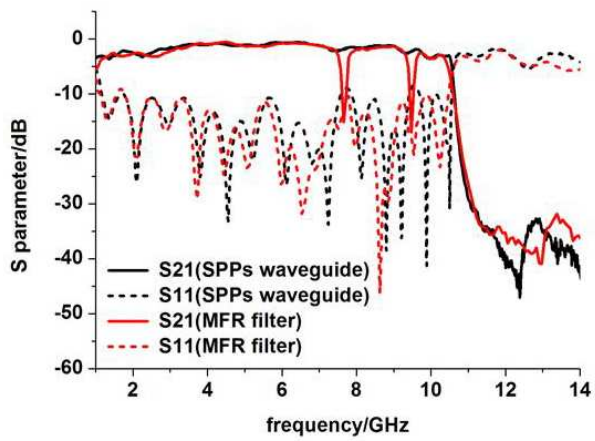

Figure 3: The measurement results of spoof SPP waveguide without ELC particles (black lines) and DFR SPP waveguide (red lines).

For the double frequencies rejection (DFR) device exhibited in Fig. 1, ELC scaling factors $k_1 = 0.7$ and $k_2 = 0.9$ are selected. The comparison of the measured results between SPP waveguide without ELCs and the DFR SPP waveguide is shown in Fig. 3, in which two clear filtering peaks at 7.65 and 9.47 GHz can be observed. Furthermore, these two rejections are in accord with the simulated results shown in Fig. 2.

We have demonstrated a double-frequency rejection device based on meliorated SPP waveguide. The filtering efficiencies of both rejections are below -15 dB and their frequencies can be designed and controlled simply by changing the sizes of ELCs, which is easy to fabricate. Our SPP rejection device has good potentials in plasmonic circuits and systems.

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