Multi-layer Transmission of Spoof Surface Plasmon Polaritons

Bai Cao Pan, **Zui Tao**, **and Tie Jun Cui**
State Key Laboratory of Millimetre Waves, School of Information Science and Engineering
Southeast University, Nanjing 210096, China

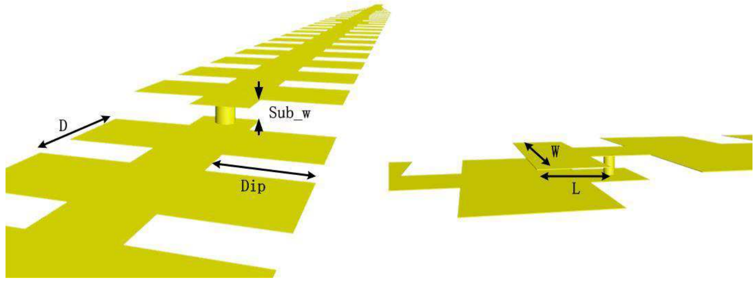
Abstract— Spoof surface plasmon polaritons (SSPPs) show a low-pass transmission property with a remarkable stop frequency due to the asymptotic property of the dispersion relationship. A series of SSPPs waveguides and their applications have been reported such as high efficiency transmission, ultra-thin waveguides and active device researches. However, in order to show more potential in combining with the traditional integrated circuits and achieve new-type plasmonic circuits, the SSPPs signal needs to be transmitted between multiple layers efficiently. Here, we propose a method to transmit such surface modes from one side of the substrate to the other side efficiently. In our design, a metallic hole inlayed inside the substrate is used to connect the traditional corrugated metallic strip waveguide on both sides of the substrate. The metallic hole could provide a decoupling effect near the transition parts between the two waveguide on different sides since the electromagnetic field distribution is remained. The simulation results show that our design could transmit the SSPPs wave from the top layer of the medium to the bottom layer without significant loss. On the other hand, through the modulation of the position of the metallic hole, a series of absorption peaks during the transmission frequency band appears because of the coupling in the superposition section of the two waveguides. It's simulated that such design could provide a broadband high-efficient multi-layer transmission with a controllable absorption and such absorption is only related to the superposition area of the corrugated metallic strip. Based on our design, SSPPs with ultra-short wavelength and high-confinement property are able to play a more important role in the plasmonic integrated circuits.

Surface plasmon polaritons (SPPs) are propagating surface modes along the interface of metal and medium with the normal component of the field decaying exponentially in the near-infrared and light frequency [1]. Such surface modes show a great confinement and much shorter wavelength property, which have been researched in a variety of areas and applications such as overcoming the diffraction limit [2], high-resolution imaging [3, 4], electromagnetically induced transparency (EIT) [5], photovoltaic improvement [6] and biosensing [7]. In 2004, Pendry et al. proposed a SPPs-like phenomenon on the surfaces perforated by holes [8]. On such basis, spoof SPPs have been designed and experimental observed both on terahertz and microwave frequency [9, 10]. In 2004, a high-efficient broadband Spoof SPPs waveguide based on ultrathin corrugated metallic strip was reported [11]. The design contains an excitation part of coplanar waveguide, a momentum matching part with gradually altering grooves and a Spoof SPP transmission part. Such waveguide provides a perfect broadband transmission property with rare loss which shows great potential for the SPP waveguide to be used in the plasmonic circuit and system applications.

Up to now, more and more applications of Spoof SPPs have been reported such as the tunable SPP filter [12] and the active circuit [13]. In order to use the Spoof SPPs in a wider area, it's of importance to combine the SPP devices and the traditional circuits. However, the traditional chip system is based on the multi-layer circuits. The transmission property of SPPs among different layers needs to be researched. In this paper, we proposed the well transmission between different layers with a metallic hole connecting the two parts of SPP waveguide. And we give the simulation results indicating that by modulating the location of the hole and the overlapping part, the waveguide could provide not only the efficient transmission but also some tunable rejecting peaks. The multi-layer transmission has great potential in applications of complex plasmonic system.

The schematic structure of the Spoof SPP waveguide is shown in Fig. 1(a). As is fully discussed in Ma's broadband highly efficient SPP waveguide, Spoof SPP modes are highly confined along such corrugated waveguide and mainly oscillate around the grooves with the component of the field inside the waveguide surface. At the transition part of a double-layer transmission where the field couples from the top side to the bottom side of the medium, the normal component of the electric field would be strengthened when the sickness of the medium gets thick, which would reduce the transmission efficiency.

Figure 2(a) shows the comparison of the transmission with and without the metallic hole when the sickness of the substrate is 0.8 mm. From the figure we can surely observed that the transmission

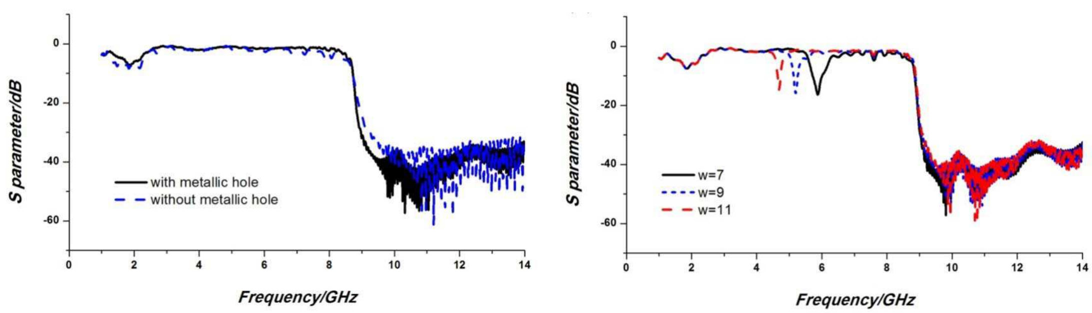


(a) (b)

Figure 1: (a) The schematic structure of the double-layer spoof SPP waveguide. (b) The Spoof SPP waveguide with an overlapping part.

efficiency is improved when the metallic hole is added especially in high frequency band. And the cut-off effect is much better with a more cliffy falling edge.

Moreover, when the waveguides on both sides of the medium have an overlapping part instead of directly connected by the metallic hole, as is shown in Fig. 1(b), a strong resonance mode would be excited. By modulating the sizes of the overlapping rectangular patch, we could control the absorption frequency caused by the resonance. Fig. 2(b) exhibits the transmission coefficient under different width of the patch w. We can obviously observe that a distinguish rejection appears within the transmission with the efficiency over $-18\,\mathrm{dB}$ and the rejection shifts to a lower frequency with the width of the patch increasing. Such controlment could also be achieved through the modulation of the length of the overlapping L.



(a) (b)

Figure 2: (a) The comparison of transmission with and without the metallic hole. (b) The absorption properties when the widths of the overlapping patch are $w = 7\,\mathrm{mm}$, $9\,\mathrm{mm}$ and $11\,\mathrm{mm}$.

We proposed a method to realize the highly efficient transmission between different layers, and achieve a controllable absorption property by adding an overlapping corrugated unit at the transition part of the SPP waveguide. The metallic hole we add between the SPP waveguides on both sides of the medium helps to increase the efficiency especially with a thicker medium. Such design has great potential in the multi-layer plasmonic circuits and systems.

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