The Investigation of Tightly Packed Spoof Surface Plasmon Polaritons Waveguides with Novel Layouts

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Abstract— **Integrated circuits (ICs) have so many advantages, such as small volume, high reliability and good performance to make it outstanding in the practical use. However, the miniaturization makes a great challenge to the signal integrity and interference suppression in ICs. Owing to the extraordinary characteristics of filed confinement and enhancement, natural surface plasmon polaritons (SPPs) at optical frequency would have potential ability to solve the aforementioned problem between miniaturization and signal integrity of ICs design. And the presentation of spoof SPPs at microwave frequency with subwavelength effect makes the idea feasible. In this paper, we proposed three different layouts of two tightly packed spoof SPPs waveguides with deep-subwavelength separation to imitate the arrangement of wires in ICs. We mainly focus on the coupling parameter of the four-port packed spoof SPPs waveguides, and make a compare with the traditional microstrip line. The optimal arrangement and separation of spoof SPPs waveguides with the lowest crosstalk whose coupling parameter remains below -20 dB in the whole transmission band have been found that could be applied in the ICs based on the SPP mode.**

Keywords—surface plasmon polariton; metamaterial; signal integrity; crosstalk;

I. INTRODUCTION

Integrated circuits (ICs) have received extensive research and application since the concept was proposed in the 50s of last century owing to its numerous advantages, such as small volume, light weight, less lead and welding points, long service life, high reliability, good performance and low cost, and being convenient for large-scale production [1]. Some scale-down technologies are applied in IC design to realize miniaturization, as a result, severe crosstalk, one of the generally occurred electromagnetic compatibility (EMC) problems in ICs [2], would happen between two closely packaged signal channels degrading the operational reliability. In a word, there are enormous challenges of signal integrity in the subwavelength circuit scale [3].

Facing the contradiction between signal integrity and miniaturization it is extremely necessary to seek some new technologies to make a balance between them. Owing to the novel abilities of field confinement and enhancement and the deep-subwavelength, surface plasmon polaritons (SPPs) has the potential to solve the EMC problem within highly integrated photonic circuits or systems [4]. However, the natural SPPs mode only comes up at the optical frequencies, because metal behaves more like plasma with negative permittivity while the dielectric is of the positive permittivity at optical frequencies, so that SPPs would form along the interface between metal and dielectric [5] and the electromagnetic field attenuates exponentially in the transverse direction. At the far-infrared and microwave frequencies, metal shows the characteristic of perfectly electrical conductors (PECs), and SPPs mode would not be stimulated naturally in those frequency bands. Based on the concept of metamaterial, which possesses novel characteristics of natural material by means of some decorations like periodic holes or grooves on it [6], spoof SPP was proposed with different forms that could mimic the properties of SPPs at optical frequencies, including 1D periodically corrugated metal film [7] , 2D conformal and ultrathin SPPs [8] and structure with 2D subwavelength drilled holes [9]. One of the 2D spoof SPPs with one-side corrugated metal film seems to be more tunable for designing the SPP characteristics at will by adjusting its geometrical parameters. Thus, the spoof SPPs could be applied to solve the EMC problems occurred in highly integrated microwave circuits to balance the miniaturization and signal integrity.

Here, two bended transmission lines are carefully designed so that the central parts close with each other and the feeding ports are separated. This model could approximately imitate the cabling in practical ICs. And we proposed three different configurations of spoof SPPs coupling lines showing in Fig.1, in which the corrugated groove directions are back-to-back, face-to-face and back-to-face, respectively. In order to make a compare with the traditional IC design, the similar coupling model with microstrip (MS) lines has been established. The scattering parameter S31 could be regarded as the coupling parameter, as S31 is higher the crosstalk is severer. Besides, we verify the coupling effect of coupling space by changing the separations of two adjacent transmission lines. And the optimal cabling and separation have been raised as a conclusion.

II. Design Procedure And Simulation

In order to propose a feasible solution to reduce the crosstalk happening between the two tightly packaged circuits in ICs, the coupling model showed in Fig.1 could properly describe the coupling effect with central coupling parts and separated feeding ports. Considering the asymmetry of one-side groove spoof SPPs transmission line, there are three layouts for coupling SPPs lines in terms of the directions of grooved side, back-to-back in Fig.1(a), face-to-face in Fig.1(b) and back-to-face in Fig.1(c), respectively. To verify the decoupling ability quantitatively, the coupling model consist of traditional microstrip lines also be constructed to be a control group showing in Fig. 1(d).

The novel properties of spoof SPPs is mainly caused by the dispersion characteristic, which could be simulated by the commercial software, CST Microwave Studio with the eigenmode solver.Fig. 2 is the schematic of spoof SPPs and its

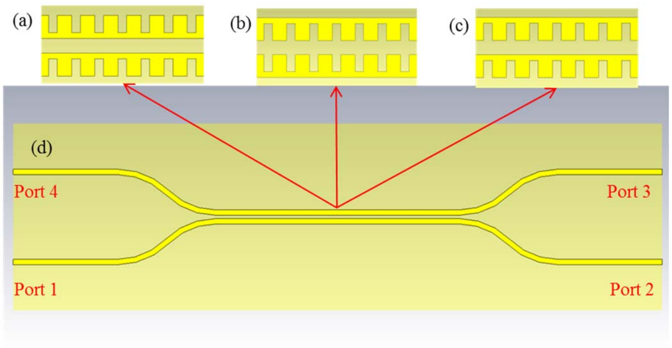

Fig. 1. (a) Back-to-back spoof SPPs coupling lines. (b) Face-to-face spoof SPPs coupling lines. (c) Back-to-face spoof SPPs coupling lines. (d) Traditional microstrip coupling lines.

dispersion curve with the compare to that of the light line in the free space and the microstrip. Here we chose Rogers RT5880 as the substrate, whose dielectric constant is 2.2, loss tangent is 0.0009, and the thickness is ts=0.787mm. And the other geometrical parameters, as showed in Fig. 2(a), are the width of the strip is h, the unit cell period is p and a groove is etched at the central unit cell with a depth of d and a width of a, while the thickness of the metallic strip is t, respectively, setting as h = 2.4 mm, p = 2.4 mm, d = 1.8mm, a = 0.9 mm, and t = 0.018 mm. The simulated dispersion diagram depicted in Fig. 2(b) shows that the dispersion curve of spoof SPPs deviates gradually from that of traditional microstrip line and further from that of light line. It is noticed that there is an asymptotic frequency which is the so-called cut off frequency at 22 GHz of spoof SPPs. Moreover, the slow wave performance of spoof SPPs becomes more significant when close to the cut off frequency.

In order to feed energy to the proposed spoof SPPs line with highly efficiency, there need to be a conversion between the traditional microwave transmission line and spoof SPPs line. It has been proved both by simulation and experiment that a matching conversion with gradient corrugations could provide the perfectly momentum and impedance matching between microstrip and the spoof SPPs [10]. Besides, bends of coupling lines are carefully designed to make the central transmission parts close to each other tightly. So a short gradient corrugated conversion connects the microstrip to the bended spoof SPPs promise that the transmission parameter S21 remains above -2 dB within the whole passband.

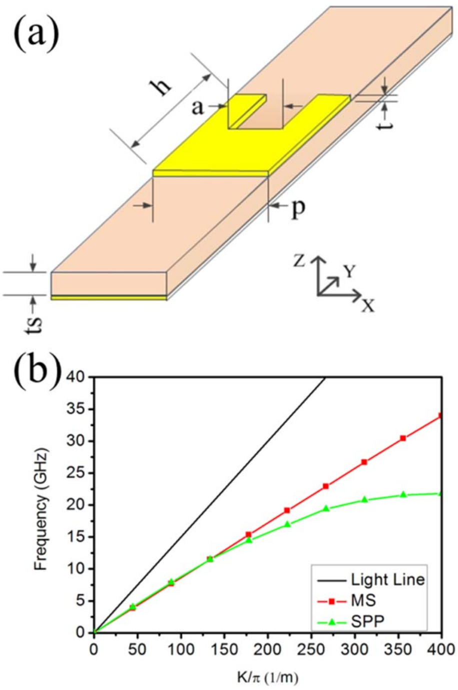

Fig. 2. (a) Schematic of spoof SPPs unit cell, in which ts=0.787mm, h = 2.4 mm, p = 2.4 mm, d = 1.8mm, a = 0.9 mm, and t = 0.018 mm. (b) Dispersion diagram of light line, traditional microstrip line and spoof SPPs.

Firstly, we compare the coupling parameters S31 of the four coupling models proposed in Fig.1 with different separations as showed in Fig. 3, 1 mm in Fig. 3(a), 1.5 mm in Fig. 3(b), 2.0 mm in Fig. 3(c) and 2.5 mm in Fig. 3(d), respectively. It is easily to understand that the coupling parameter could quantitatively evaluate the crosstalk of the tightly packaged lines.

As the separations increased, S31 of the three coupling spoof SPPs lines bring down apparently, that means the crosstalk of the three coupling spoof SPPs reduce, while that of the traditional coupling microstrip lines basically keeps the same amplitude. Theoretically speaking, the coupling of back-to-back spoof SPPs lines mainly tend to be that of the coupling microstrip.

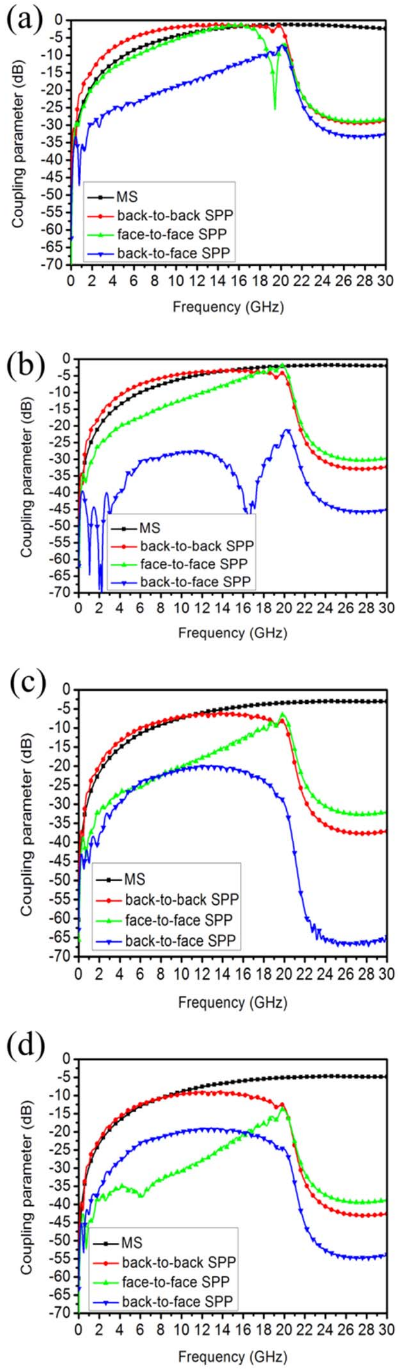

Fig. 3. Compare of coupling parameter with different separations (a) 1 mm. (b) 1.5 mm. (c) 2.0 mm. (d) 2.5 mm.

Furthermore, the thinner strip have looser field confinement, so the energy is more easily to leak from one channel to another to make much more crosstalk. As a result, the coupling parameter of back-to-back spoof SPPs line is higher than microstrip coupling lines, especially at lower frequencies. Overall, the performances of anti-crosstalk of face-to-face and back-to-face spoof SPPs coupling lines are better than the microstrip lines and back-to-back spoof SPPs lines and the coupling parameters overall rise as the frequencies increase [11].

It is notable that the back-to-face spoof SPPs lines has the best performance to reduce the crosstalk keeping S31 below -10 dB within the whole passband, and there are more than 10 dB decrease with separations changing from 1.0 mm to 2.5 mm. For more precisely, there is an optimal separation for back-to-face spoof SPPs coupling lines at 1.5 mm with the lowest crosstalk than smaller or bigger separations and with S31 below -20 dB. More importantly, the form of back-to-face spoof SPPs is so compact that the same direction of corrugations between the adjacent circuits provide an extremely convenience for ICs or chip design.

III. CONCLUSION

In this paper we construct three layouts of spoof SPPs coupling lines, back-to-back, face-to-face and back-to-face, respectively, to investigate their performances of anti-crosstalk, and make compare to that of the traditional microstrip coupling lines with the same geometrical parameters. The simulation results indicate that the back-to-face spoof SPPs coupling lines has the best performance to reduce the crosstalk, and that form has great benefit to integrate with ICs. Owing to the extraordinary deep-subwavelength property of spoof SPPs, it could draw a conclusion that back-to-face spoof SPPs coupling lines have great potential to be applied to ICs or chip design to solve the contradiction between signal integrity and miniaturization.

ACKNOWLEDGMENT

This work was supported in part from the National Science Foundation of China under Grant Nos.61631007, 61571117, 61501112, 61501117, 61522106, 61722106, 61701107, and 61701108, and 111 Project under Grant No.111-2-05.

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