Bandpass Filter Based on Spoof Surface Plasmon Polaritons and Substrate Integrated Waveguide

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***Abstract* – A bandpass filter based on novel spoof surface plasmon polaritons (SSPPs) and substrate integrated waveguide (SIW) is reported. The filter consists of a conventional SIW structure and a ring slot array etched on the top metal layer of the SIW to excite SSPP modes. The passband of the filter can be adjusted by changing the dispersion characteristics, which can be realized by tuning the specific parameters of the unit cell. The simulation results indicated that the proposed structure has great filter characteristics within a passband from 13 to 24.1 GHz with minimum insertion loss of 0.42 dB at 17.8 GHz.**

***Index Terms* —Bandpass filters, spoof surface plasmon polaritons (SSPPs), substrate integrated waveguide (SIW), ring slot.**

I. Introduction

In recent years, the ultra-thin spoof surface plasmon polaritons (SSPPs) provides a new idea for the design of bandpass filters, frequency splitters and antennas [1]-[5]. On the one hand, ultra-thin SSPPs have already been proved to own strong ability to confine surface electromagnetic (EM) waves that propagate along the interface of metal and dielectric in microwave band, which is similar to that of SPPs in visible or ultraviolet (UV) band [6]. On the other hand, the application of ultra-thin SSPPs overcomes the problem that it is difficult to integrate the original 3D SSPPs into planar circuit design in the early stage [7].

Unfortunately, the conventional ultra-thin SSPPs are constructed by corrugated strip lines, which are all open structures. Thus, the radiation loss and mutual coupling with other transmission lines or devices are unavoidable [8]. Substrate integrated waveguide (SIW) has been widely applied in the design of microwave components and circuits for its advantages of low loss, low profile, slight crosstalk and so on.

In this paper, a new SSPP unit cell structure is proposed using a ring slot and a via integrated with SIW. The dispersion characteristics of the proposed SSPP are studied and analyzed. It shows that the low and high cut-off frequencies can be adjusted by tuning the width of unit cell and the radius of ring slot, respectively. Finally, the frequency responses of the proposed filter are simulated and optimized, with a good bandpass filtering effect and low insertion loss in a wide frequency band.

II. Analysis of The Proposed SSPP

The proposed SSPP structure consists of a conventional SIW with the periodic array of a ring slot on the top metal layer and a via hole. The center part of the ring slot is connected with the ground through the via hole for each SSPP unit cell. The configuration of the proposed SIW-SSPP unit cell is shown in Fig. 1. The yellow and blue area denote the copper with thickness 0.035 mm and F4B substrate with relative dielectric constant $\varepsilon_r = 2.65$, loss tangent $\tan\delta = 0.01$ and thickness of 0.5 mm, respectively. To further understand the characteristics of the proposed SSPP structure, its dispersion curves are analyzed. The parameters of the SSPP unit cell are set as follows: $W = 8.2$ mm, $p = 2.5$ mm, $g = 0.85$ mm, $d_{outer} = 2.3$ mm, $d_{inner} = 2$ mm, $d_{slot\_1} = 0.5$ mm, $d_{slot\_2} = 0.5$ mm.

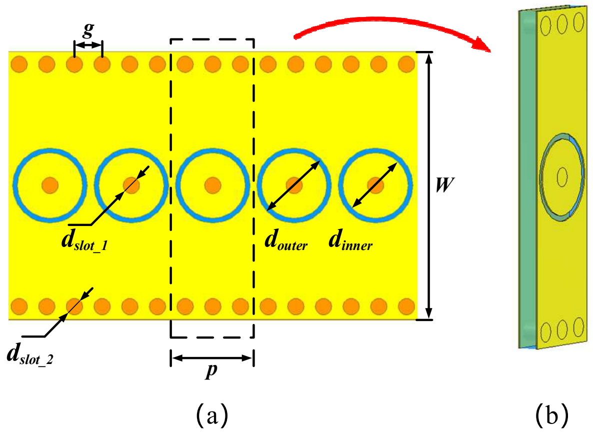

Fig. 1. Schematic view of proposed SSPP structure with SIW. (a) Top view. (b) 3D view of the proposed unit cell.

The dispersion curves for the fundamental mode of the proposed SSPP unit cell with different values of p, different values of W, and different values of d_{inner} are shown in Fig. 2(a), Fig. 2(b), and Fig. 2(c), respectively. In order to further observe the characteristics of dispersion curves with different radii of the ring slot without variation of the ring slot width, different combinations of d_{outer} and d_{inner} with the same ring slot width (0.15 mm) are selected in simulation.

It can be observed from Fig. 2(a) and (c) that the upper cut-off frequencies of the proposed unit cell decrease as p and radius of ring slot increase while the lower cut-off frequencies remain the same. From Fig. 2(b), it can be seen that the higher

W values cause lower cutoff frequencies, while upper cut-off frequencies are not affected by the variations of W at all. Fig. 2(d) indicates that the parameter d_{inner} has an inverse effect on the upper and lower cut-off frequencies in the dispersion curves at the same time. Meanwhile, compared with the lower cut-off frequencies, the upper cut-off frequencies are more sensitive to the variation of d_{inner}.

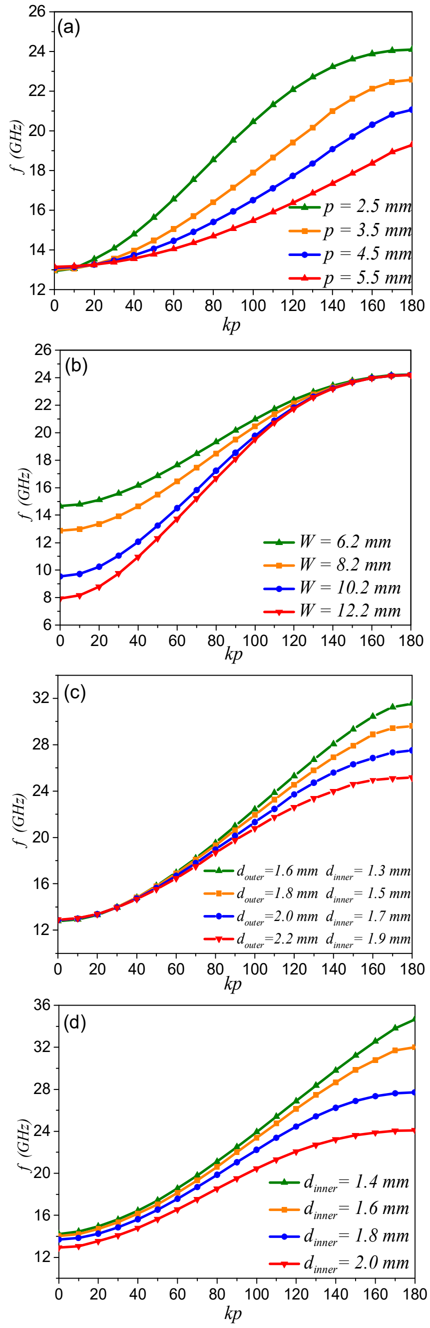

Fig. 2. Dispersion curves of the proposed unit cell (a) with different p. (b) with different W. (c) with different combinations of d_{outer} and d_{inner}. (d) with different d_{inner}.

Based on the above analysis of dispersion curves, the p and radius of ring slot can be used to tune the upper cut-off frequency for the passband in BPF design. Similarly, the lower cut-off frequency of passband can be adjusted by the change of W independently. Geometrical parameter d_{inner} can be used to control the upper and lower cut-off frequency of the BPF entirely.

III. Bandpass Filter Application

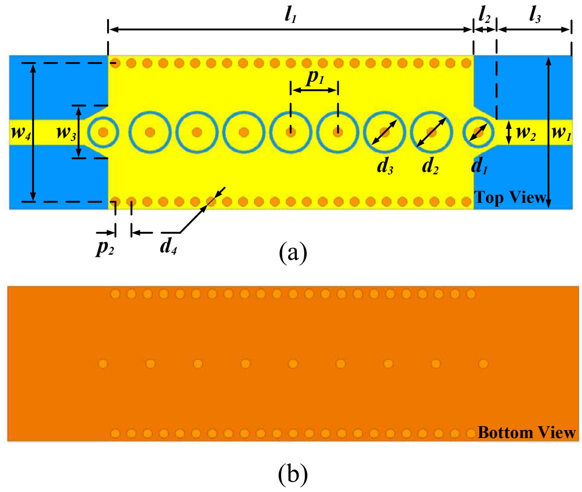

Fig. 3. Schematic view of proposed filter. (a) Top view. (b) Bottom view.

The configuration of the proposed BPF is shown in Fig. 3. The filter consists of microstrip part, transition part and SSPP transmission part. In the transition part, a tapering microstrip line and a smaller ring slot are used for matching the impedance between 50-Ohm microstrip line and proposed SSPP structure. The S-parameters are optimized by Ansoft HFSS and the simulation results are presented at Fig. 4. The final parameters of the BPF layout are set as follows: l_1 = 19.5 mm, l_2 = 1.25 mm, l_3 = 4 mm, w_1 = 8.2 mm, w_2 = 1.35 mm, w_3 = 2.75 mm, w_4 = 7.4 mm, d_1 = 1.4 mm, d_2 = 2.3 mm, d_3 = 2 mm, d_4 = 0.5 mm, p_1 = 2.5 mm, p_2 = 0.85 mm.

As shown in Fig. 4, the BPF possesses good bandpass characteristic from 13 GHz to 24.1 GHz, and. The minimum insertion loss is -0.42 dB at 17.8 GHz.

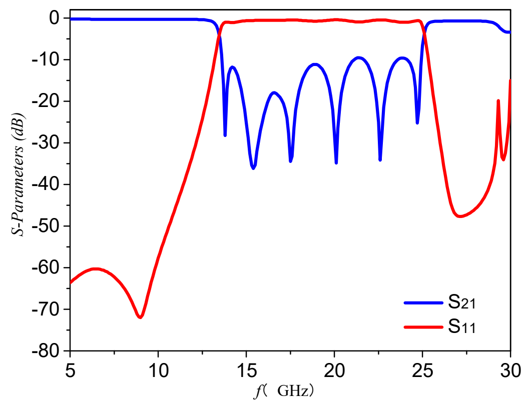

Fig. 4. Simulated S-parameters of the proposed filter.

IV. Conclusion

In this paper, a BPF based on the novel SSPP integrated with SIW is proposed and analyzed. The lower and upper cut-off frequency of the bandpass for BPF can be adjusted flexibly. The simulated result shows that the BPF possesses a bandwidth from 13 GHz to 24.1 GHz with 0.42 dB minimum insertion loss at 17.8 GHz. The BPF do not only have good filtering characteristics but also be potential for the on-chip integrated devices designed.

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References

[1] J. Shibayama, J. Yamauchi, and H. Nakano, "Metal disc-type splitter with radially placed gratings for terahertz surface waves," *Electron. Lett.*, vol. 51, no. 4, pp. 352–353, 2015.

[2] Y. Guo., K. Xu., X. Deng, X. Cheng, and Q. Chen, "Millimeter-wave on-chip bandpass filter based on spoof surface plasmon polaritons," IEEE Electron Device Lett., vol. 41, no. 8, pp. 1165-1168, Aug. 2020.

[3] A. Kianinejad, Z. N. Chen, and C. W. Qiu, "A single-layered spoof-plasmon-mode leaky wave antenna with consistent gain," IEEE Trans. Antennas Propag., vol. 65, no. 2, pp. 681–687, Feb. 2017.

[4] K. Xu, S Lu, Y. Guo, and Q. Chen, "High-order mode of spoof surface plasmon polaritons and its application in bandpass filters," IEEE Trans. Plasma Sci., vol. 49, no. 1, pp. 269-275, Jan. 2021.

[5] K. Xu, Y. Guo, Q Yang, Y Zhang, X Deng, A Zhang, and Q Chen, "On-chip GaAs-based spoof surface plasmon polaritons at millimeter-wave regime," IEEE Photon. Technol. Lett., vol. 33, no. 5, pp. 255-258, 2021.

[6] J B Pendry, L. Martin-Moreno, F J Garcia-Vidal. "Mimicking surface plasmons with structured surfaces,". Science, vol. 305, no. 5685, pp. 847-848, Aug. 2004.

[7] X. Shen, T. Cui, D. Martin-Cano, et al. "Conformal surface plasmons propagating on ultrathin and flexible films," Proc. Nat. Acad. Sci , vol. 110. no. 1, pp: 40-45. 2013.

[8] D. Guan, Y Peng, Q. Zhang, et al. "Hybrid Spoof Surface Plasmon Polariton and Substrate Integrated Waveguide Transmission Line and Its Application in Filter," IEEE Trans. Microw. Theory Techn., vol. 65. pp:1-8, Dec. 2017.