A high-resolution sensor using active plasmonic metamaterials

Jing Cai[1], Yong Jin Zhou[1,2,*] , and Qiao Yu Li[1]
[1]Key Laboratory of Specialty Fiber Optics and Optical Access Networks, Joint International Research Laboratory of Specialty Fiber Optics and Advanced Communication, Shanghai Institute for Advanced Communication and Data Science, Shanghai University, Shanghai 200444, China
[2]State Key Laboratory of Transducer Technology, Chinese Academy of Sciences, Shanghai 200050, China
*e-mail address: yjzhou@shu.edu.cn

***Abstract*—A high-resolution sensor operating at microwave frequencies has been proposed, which are composed of textured ring structures with the bias circuit and the amplifier chip. Simulated and experiments have been conducted. It has been shown that the quality factor of the proposed structure can be greatly enhanced by the active amplified circuit, which results in clear differences in various concentrations of ethanol. The proposed sensor has advantages of compactness and high resolution as well as compatibility with lab-on-a-chip platforms.**

Keywords—liquid sensor; active amplified circuit; plasmonic; spoof LSPs; high resolution

I. INTRODUCTION

Surface plasmons (SPs), which could be divided into the surface plasmon polaritons (SPPs) in extended interfaces and localized surface plasmons (LSPs) in finite metal particles, attracted a great deal of interest due to their novel properties of deep subwavelength confinement and field enhancement [1]. However, when the frequency of the incident light drops to microwave and terahertz regions, metallic behaves similarly to perfect electric conductors (PEC) which do not supports the SPs.

In order to satisfy the needs of various applications at low frequencies, the concept of spoof SPPs based on the structured metal surfaces has been proposed [2] and textured closed surfaces [3] can support spoof LSPs with properties resembling those of LSPs in the optical regime is theoretically demonstrated. Subsequently, the spoof LSPs have been experimentally verified on an ultrathin planar metallic structure at microwave frequencies [4]. After that, various kinds of devices based on spoof LSPs have been designed, such as corrugated ultrathin fan-shape metallic strips [5], and metallic spiral structure [6], and closed subwavelength high contrast gratings [7]. However, due to low resonance intensity and special excitation of these structures, they are hard to use in practice. Although these questions can be solved by some planner excitation, like microstrip line [8] and flared slot line [9], quality factors (Q value) of resonance peaks is hard to get a significant boost due to their inherent loss.

In this paper, we firstly proposed an active textured metal resonator based on spoof LSPs, enhancing its Q value significantly by using the amplified circuit to make up the metal loss. Subsequently, a high-resolution sensor loaded amplifier chip has been designed, the amplifier chip could greatly compensate the metal loss and the loss of injected liquid, showing a high resolution for liquid detection. The proposed sensor has advantages of compactness and high resolution as well as compatibility with lab-on-a-chip platforms.

II. DESIGNE AND RESULTS

A. Textured ring resontaor with a slit

Fig.1 depicts the schematic configuration of the proposed resonator, which consist of the corrugated ring with a slit. For the textured ring (top metal layer), the number of the grooves N is 40, the radius r is 12 mm and the central strip width g is 1 mm. The groove height, period, and width of the metal corrugated strip are set to be h = 5 mm, $p = 2\pi(r+g+h)/N = 2.83$ mm, and $a = 0.4\times p = 1.13$ mm, respectively. The microstrip lines, shown as black dashed lines in Fig. 1 (middle metal layer) are used to excite the textured ring, whose length l_s and width w_s are 13 mm and 1.1 mm, respectively. In order to minimize the reflected power, the radius r_1=2 mm of the metallic disk is placed at the end of the microstrip line. The thickness t of all three metal layers is 18 μm, and the dielectric substrate is Rogers RO4350, whose total thickness d is 1.016 mm and relative dielectric constant is 2.66. There is a difference in Ref [8], the proposed metal ring has a slit in 45degree direction of microstrip line, which enhance the resonance to improve the Q value.

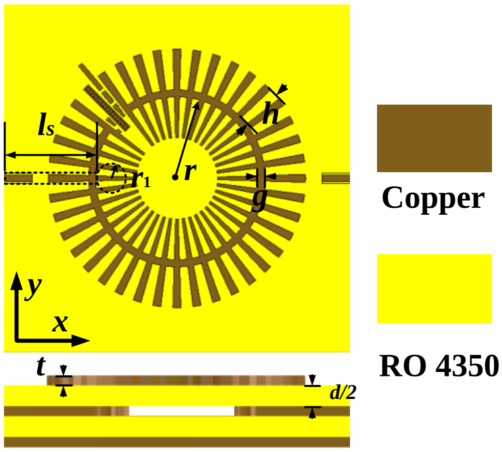

Fig. 1. The schematic configuration of the textured metal ring with a slit.

The simulated and measured S-parameters are illustrated in Fig.2, it shows that experimental results are almost identical with simulation results.

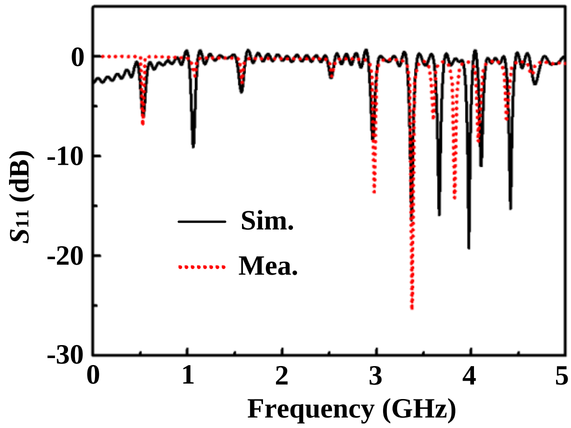

Fig. 2. The simulated and measured S-parameters of the resonator

B. The proposed resonator loading amplifier chip

Fig.3 depicts the schematic configuration of the proposed resonator loading amplifier chip, and the detailed structure of the bias circuit is given in the inset, where the black circles represent metallic via-holes connecting to the ground plane (bottom metal layer) and the metallic pads are used to weld the lumped components. Active amplified circuit (AC) could make up the inherent loss of the proposed resonator, therefore the quality factor should be enhanced.

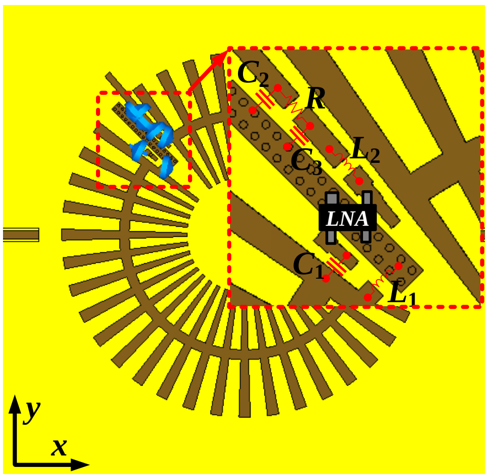

Fig. 3. The schematic configuration of the proposed resonator with active AC.

The measured S_{11} of the active textured ring with bias voltage (BV) is shown in Fig.4, where the BV of the amplifier chip is 0V (no BV) or 5V, it can be seen that the resonant modes are amplified significantly and the resonant frequencies slightly shifts compare with the structure without amplifier chip (the red dotted line) due to the introduction of the active amplified circuit.

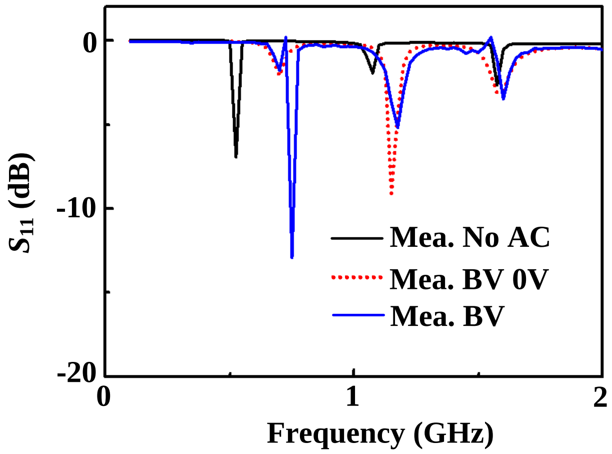

Fig. 4. The measured S-parameters of these cases: without AC, without BV and with BV, respectively.

III. Conclusion

In this paper, we firstly proposed an active textured metal resonator based on spoof LSPs, enhancing its Q value significantly by using the amplified circuit to make up the metal loss. Subsequently, a high-resolution sensor loaded amplifier chip has been designed, the amplifier chip could greatly compensate the metal loss and the loss of injected liquid, showing a high resolution for liquid detection. The proposed sensor has advantages of compactness and high resolution as well as compatibility with lab-on-a-chip platforms.

Acknowledgment

This work was supported in part by the National Natural Science Foundation of China under Grant No. 61307129, and in part by Science and Technology Commission of Shanghai Municipality (STCSM) under Grants No. 18ZR1413500 and SKLSFO2017-05.

References

[1] F. J. Garciavidal, L. Mart ínmoreno, J. B. Pendry, “Surfaces with holes in them: new plasmonic metamaterials,” J. Opt. A Pure Appl. Op., vol. 7(2), pp. S97, February 2005.

[2] X. P. Shen, T. J. Cui, D. Martin-Cano, et al. “Conformal surface plasmons propagating on ultrathin and flexible films,” P. Natl. Acad. Sci. USA., vol. 110(1), pp. 40-45, January 2013.

[3] A. Pors, E. Moreno, L. Martinmoreno, et al. “Localized spoof plasmons arise while texturing closed surfaces,” Phys. Rev. Lett., vol. 108(22), pp. 223905, January 2012.

[4] X. P. Shen, T. J. Cui, “Ultrathin plasmonic metamaterial for spoof localized surface plasmons,” Laser Photonics Rev., vol. 8(1), pp. 137-145, January 2014.

[5] Z. Gao, F. Gao, H. Xu, et al. “Localized spoof surface plasmons in textured open metal surfaces,” Optics Letters, vol. 41(10), pp. 2181, May 2016.

[6] P. A. Huidobro, E. Moreno, L. Martin-Moreno, et al. “Magnetic localized surface plasmons,” Phys. Rev. X., vol. 4(2), pp. 340-342, March 2014.

[7] Z. Li, B. Xu B, L. Liu, et al. “Localized Spoof Surface Plasmons based on Closed Subwavelength High Contrast Gratings: Concept and Microwave-Regime Realizations,” Sci. Rep., vol. 6, June 2016.

[8] B. J. Yang, Y. J. Zhou, Q. X. Xiao, “Spoof localized surface plasmons in corrugated ring structures excited by microstrip line,” Opt. Express, vol. 23(16), pp. 21434-42, August 2015.

[9] Q. X. Xiao, B. J. Yang, Y. J. Zhou, “Spoof localized surface plasmons and Fano resonances excited by flared slot line,” J. Appl. Phys., vol. 118(23), pp. 824, December 2015.