A NOVEL METAMATERIAL MICROFLUIDIC SENEOR FOR BIOCHEMICAL SENSING

Hong Zhou[1,2,3], Donglin Hu[1,2,3], Jia Gong[1,2,3] ,Junwang Ji[1,2,3], Xu Liu[1,2,3], Zhengguo Shang[1,2,3], Yu Chen[4] and Xiaojing Mu[1,2,3,*]

[1] Defense Key Disciplines Lab of Novel Micro-nano Devices and System Technology，Chongqing University, Chongqing, China

[2] International R & D center of Micro-nano Systems and New Materials Technology，Chongqing University, Chongqing, China

[3] Key Laboratory of Optoelectronic Technology & Systems, Ministry of Education, Chongqing University, Chongqing, China

[4]Institute of High Performance Computing, Agency for Science, Technology and Research, Singapore

* Email: mxjacj@cqu.edu.cn; Tel.: +86-15902396712

This paper presents a novel metamaterial micro-fluidic sensor with two pairs of symmetrical double split-ring resonators (DSRR) compared to state of the art, which exhibits unique high-Q (~653) resonance and a 34% higher S21 magnitude than a single DSRR and allow, for the first time, real-time dual-channel biochemical testing through the design of two micro channels underneath the metamaterial DSRR. Polyimide was chosen as the substrate material and it shows good temperature stability at -200~300 ℃, which makes the sensor enabling to work in harsh environment.

Biochemical sensors based on metamaterial DSRR are studied by many groups. Prior work on a similar fabrication process was reported at Sensors and Actuators A [1]. Analytical Modeling of the DSRR was reported at Electromagnetics [2]. Our sensor differs from that of group W Withayachumnankul [3] in the structural design, and of group Minyeong Yoo [4] in the working principles and substrate material.

The proposed sensor consists of Au microstrip lines, Au DSRR, microfluidic channels, polyimide substrates and Au bottom layer, as shown in Fig. 1 (DSRR dimension: larger ones, a_1=0.2, b_1=0.2, c_1=0.2, d_1=0.2, e_1=0.2, R_1=0.73; smaller ones, a_2=0.18, b_2=0.18, c_2=0.18, d_2=0.18, e_2=0.2 R_2=0.53, unit: mm). In general, there are two ways to analyze the performance of the sensor: finite element analysis (FEA) and equivalent circuit analysis (ECA). The finite element simulation is realized by Ansoft HFSS, and the simulation results are shown in Fig. 2. It reveals that the S21 amplitude of a sensor with a pair of symmetrical DSRRs is 34% higher than that of a sensor with a single DSRR. Fig. 3(a) (b) shows the schematic electromagnetic field distribution of a microstrip transmission line with a pair of DSRR and Electrical components of DSRR element respectively, and figure 3 (c) is an equivalent circuit model that can be used to analyze the proposed sensor.

The experimental setup is outlined in Fig. 4(a) and the sensor is fabricated by using standard photolithography and chemical etching. The data of FEA and ECA as shown in Fig. 4(b) are in good agreement with the measured results. In addition, it can be seen from the figure that there is no interaction between channel A and channel B. When the concentration of ethanol is changed from 0% to 100% (10% one step), the resonant frequency of the proposed sensor is observed to shift from 6.20 to 7.21 GHz (black solid) for channel A and 9.82 to 10.89 GHz (blue solid) for channel B, as shown in Fig.5. At the same time, it shows that the linearity of the sensor looks well. In conclusion, it is obvious that this dual-channel metamaterial micro-fluidic sensor could be a good option for real-time chemical analysis. Moreover, when a biological sample is coated on the surface of the gold DSRR, the sensor has potential for biosensing.

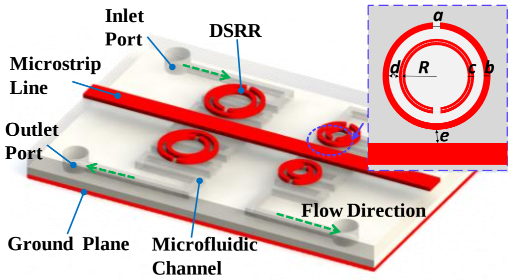

Fig.1 Schematic diagram of the metamaterial micro-fluidic sensor and the size of DSRR.

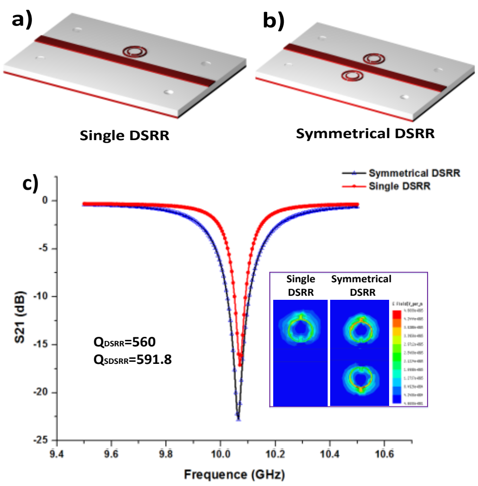

Fig.2 Schematic diagram of metamaterial sensor with (a) single DSRR, or (b) symmetrical DSRR, and (c) simulated results of the DSRR sample and distribution of surface current density (right inset)

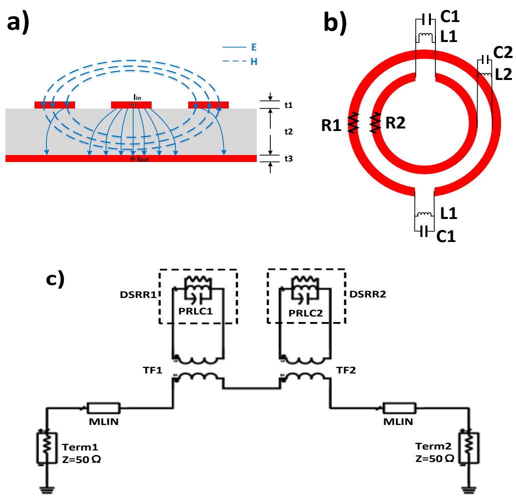

Fig.3 (a) Cross section of a microstrip transmission line with a pair of DSRR and a schematic electromagnetic field distribution, (b) Electrical components of DSRR element, (c) equivalent circuit of the metamaterial sensor.

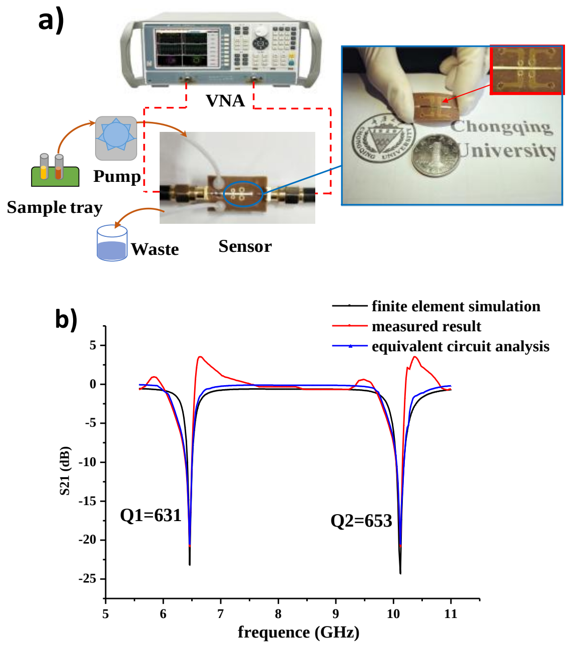

Fig.4 (a) Diagram of the experimental setup and the proposed sensor, (b) the results of finite element simulation (black solid), equivalent circuit analysis (blue solid) and experiment (red solid).

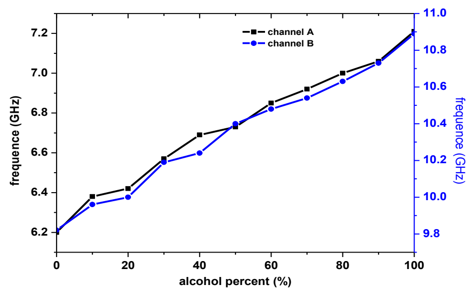

Fig.5 Resonant frequency for ethanol in channel A (black solid) and channel B (blue solid) with different concentrations, from 0% (DI water 100%) to 100%.

REFERENCES

[1] W Withayachumnanku, "Metamaterial based microfluidic sensor for dielectric characterization." Sens. Actuators A, **2013**

[2] B. Sauviac, C. R. Simovski, and S. A. Tretyakov. "Double Split-Ring Resonators: Analytical Modeling and Numerical Simulations." Electromagnetics, **2004**

[3] W. Withayachumnanku, "Metamaterial Inspired Multichannel Thin-Film Sensor." IEEE Sensors Journal **2011**, 12, 1455-1458.

[4] M. Yoo, H. K. Kim, "Electromagnetic based ethanol chemical sensor using metamaterial absorber", Sens. Actuators B, **2016**,