Microfluidic Chemical Sensor based on SIW Cavity

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***Abstract*- This paper presents a substrate- integrated-waveguide (SIW) cavity resonator with an introduction of a microfluidic channel to achieve a non-contact sensor for chemical sensing applications. The dominant mode resonant frequency of the cavity resonator is switched by injecting a very small amount of liquid (chemical) into microfluidic channel, which further results in a change in the effective dielectric constant. Initially, the two layers of SIW resonator are constructed, and then the microfluidic channel is etched on Polydimethylsiloxane (PDMS) material stuck between the two SIW layers for non-contact chemical sensing applications. S-parameters of the proposed SIW resonator are simulated and measured. The dominant mode frequency of the proposed structure is successfully switched from 18.46 GHz to 14.83 GHz when ethanol is injected and the frequency becomes 14.11 GHz when DI-water is injected into the microfluidic channel. The capability of the SIW cavity resonator to function as a chemical sensor is successfully demonstrated.**

***Index Terms* — resonator, chemical sensor, SIW, microfluidics, ethanol.**

1. Introduction

Chemicals and many liquid materials have been detected with ease for several decades now by using chemical sensors. These sensors assist the organization of chemical and liquids on a wide range for industrialized purpose. Chemicals should be categorized, stored and organized as per Globally Harmonized System (GHS). Using unidentified and unlabeled liquids in experimental processes can have serious concerns since some of the chemicals are hazardous and have severe side-effects on a human skin. For instance, methyl-alcohol is dangerous for a humans and can be the reason for diseases like blindness, coma, or even can cause death [1]. Consequently, all chemical liquids, either hazardous or not should always be known and labeled properly. Furthermore, a material safety data sheet (MSDS) must be kept on the shelf containing chemicals.

Usually the sensors used for measuring water class or for analyses of bioassays or chemical assays require large amount of liquid for filling tubing or valves [2], [3]. Thus, majority of the liquid used is not consumed and it is discarded during the process. To control this waste and to elucidate this issue of discarding left-over liquids or chemicals, a fluidic or microfluidic approach has been addressed. A silicon-microfabricated diffusion-based optical chemical sensor was presented in order to detect chemical concentration [4]. This optical sensor can observe an analytic concentration at minimum amount of volume for a complex sample. Moreover, the liquid-core optical ring-resonator sensor was presented in [5]. Where, a fused silica capillary carries out aqueous sample and works as a ring resonator. Ring resonator's optical characterization is carried out with an ethanol-water combination.

RF components also allow integration of microfluidic channels for different sensing applications [6]. A microwave and microfluidic resonator sensor was presented in [6]. The advantage of microfluidic channel is that it makes a convenient environment to gather measurement data in a nanoliter amount of liquid. Which implies that a resonant frequency of an RF circuit can be switched and sensed by the injection of a nanoliter liquid.

In our research, a non-contact microfluidic cavity resonator is suggested for chemical sensing. The initial structure is designed using substrate-integrated-waveguide (SIW) technology, which provides various advantages: 1) low loss, 2) high *Q*-factor, and 3) light weight [8]. Here, in our proposed research, a microfluidic channel is constructed on the Polydimethylsiloxane (PDMS) slab which is then incorporated between two SIW layers from top and bottom to achieve higher frequency shifting ability. Hence, the resonant frequency of structure is widely switched by the injection of a very small amount of liquid sustained at the center position of the SIW inside microfluidic channel.

2. Microfluidic SIW Resonator Design

SIW planar structures are simple in fabrication and they can be cascaded with millimeter-wave and microwave integrated circuits (ICs) as printed circuit boards (PCBs). Fig. 1 shows the layout of the proposed SIW chemical sensor. The resonant frequency is switched by injecting ethanol and DI-water chemicals into the microfluidic channel, which is constructed on the middle layer (PDMS) at a location which corresponds

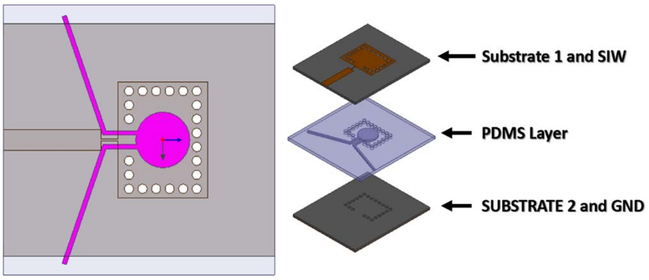

Fig. 1. Layout of the proposed SIW Resonator

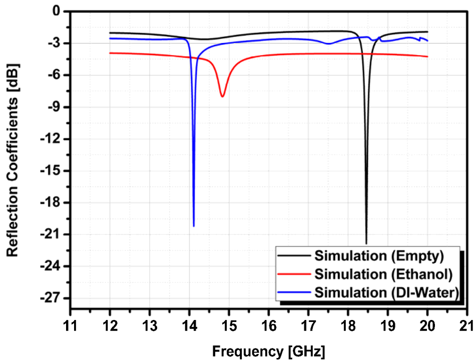

Fig. 2. Simulated Reflection Coefficients for empty, ethanol and DI-water cases

to the center of SIW (maximum electric field). The proposed structure has 3 layers as shown in Fig. 1, two of them are built on Rogers Duroid 5870 substrate, which has a dielectric constant $\mathcal{E}_r$ of 2.2 and a thickness *h* of 0.79 mm.

3. Simulation and Measurement Results

A full-wave simulation is performed by an ANSYS high frequency structure simulator (HFSS) and measurements are taken in laboratory using Vector Network Analyzer (VNA). Fig. 2 shows the simulated reflection coefficients for three states of the structure where microfluidic channel designed on the middle layer (PDMS) is either: (a) empty, (b) filled with ethanol filled, or (c) DI-Water filled.

Fig. 3 shows the fabricated prototype of the proposed SIW chemical sensor. Top and bottom layers were fabricated through PCB etching process using Rogers Duroid 5870 substrate, which has a dielectric constant $\mathcal{E}_r$ of 2.2 and a thickness *h* of 0.79 mm., middle layer PDMS (with microfluidic channel) was made laser etching machine. All three layers were combined as a sandwich by sticking adhesive bonding film. After combining the three layers, SIW vias were constructed using a drill and further vias were fixed into all three layers as shown in Fig. 3.

Fig. 4 shows simulated and measured reflection coefficients of the proposed SIW chemical sensor for the three states of empty, ethanol and DI-water. As seen from reflection coefficients result, frequency is clearly shifted from 18.46 GHz to 14.83 GHz when an ethanol chemical is injected and frequency is even further moved to 14.11 GHz when DI-water is injected into the microfluidic channel from an empty state. Fig. 4 shows a good agreement of measured results with simulation results for all three states carried out during experiment in our laboratory.

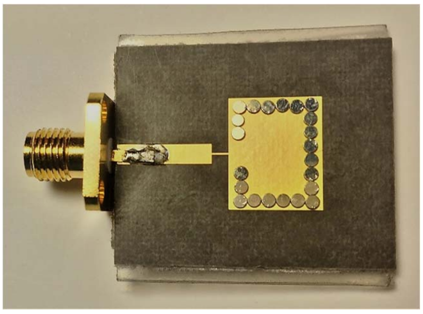

Fig. 3. Photograph of the fabricated prototype

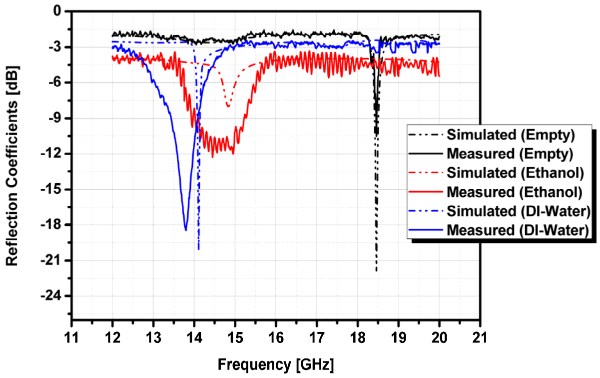

Fig. 4. Comparison of simulation and measurement results for empty, ethanol and DI-water cases

4. Conclusion

It is successfully demonstrated that the resonant frequency of an SIW structure is switched enormously when any of the two chemicals are injected in the microfluidic channel on PDMS layer of structure. This makes our proposed sensor suitable for any chemical detection. It can also be commercially used as a low concentration sensor for applications which require sensing of chemicals having as less as 0.01% concentrated chemicals.

Acknowledgment

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References

[1] G. Wen, X. Wen, S. Shuang, and M. M. F. Choi, “Whole-cell biosensor for determination of methanol,” *Sensors Actuators B Chem.*, vol. 201, pp. 586–591, Oct. 2014.

[2] W. M. Mullett, K. Levsen, D. Lubda, and J. Pawliszyn, “Bio-compatible in-tube solid-phase microextraction capillary for the direct extraction and high-performance liquid chromatographic determination of drugs in human serum,” *J. Chromatogr. A*, vol. 963, no. 1–2, pp. 325–334, Jul. 2002.

[3] R. Dahlgren, E. Van Nieuwenhuyse, and G. Litton, “Transparency tube provides reliable water-quality measurements,” *Calif. Agric.*, vol. 58, no. 3, pp. 149–153, 2008.

[4] B. H. Weigl and P. Yager, “Silicon-microfabricated diffusion-based optical chemical sensor,” *Sensors Actuators B Chem.*, vol. 39, no. 1–3, pp. 452–457, Mar. 1997.

[5] I. M. White, H. Oveys, and X. Fan, “Liquid-core optical ring-resonator sensors,” *Opt. Lett.*, vol. 31, no. 9, pp. 1319–1321, 2006.

[6] T. Chretiennot, D. Dubuc, and K. Grenier, “A Microwave and Microfluidic Planar Resonator for Efficient and Accurate Complex Permittivity Characterization of Aqueous Solutions,” *Microwave Theory and Techniques, IEEE Transactions on*, vol. 61, no. 2. pp. 972–978, 2013.

[7] S. K. Pavuluri, “Integration of microfluidic channels with frequency selective surfaces for sensing and tuning,” in *The 8th European Conference on Antennas and Propagation (EuCAP 2014)*, 2014, pp. 133–136.

[8] M. U. Memon and S. Lim, “Review of reconfigurable substrate-integrated-waveguide antennas,” *J. Electromagn. Waves Appl.*, vol. 28, no. 15, pp. 1815–1833, 2014.