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Microwave Sensor within a Microfluidic Chip for Biological Applications †

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Abstract: A miniaturized sensor operating in Radio Frequency region (RF) is proposed to address the need in picoliter liquid characterization. The sensor is based on a coplanar waveguide (CPW) combined with a microfluidic channel dedicated to microliter liquid characterization with perspectives for biology and single cell characterization. Using microtechnology process, the sensor has been designed on a 0.5 mm thick quartz wafer with Cr/Au electrodes. A prototype of the sensor has been fabricated and evaluated with ethanol/water mixtures at different molar fractions of ethanol. A good agreement between theoretical and measured electrical response of the sensor is observed.

Keywords: RF characterization; RF sensors; liquids; picoliter volumes; microfluidic; broadband; dielectric characterization

1. Introduction

Electromagnetic techniques have become popular in biomedical applications as they allow rapid, non-invasive and easily automated characterization. For these reasons, in the last decade intensive works have been devoted to develop RF and microwave sensors [1–6]. They are compatible with biological environments and allow characterizing very small volumes. Classically, the open-ended coaxial probe approach is most commonly used for complex permittivity [7]. However, this method requires relatively large sample volumes (few mL) and is not suitable to RF characterization at single cell scale. As an alternative, coplanar waveguide (CPW) sensors have been proposed [8–10], however the volumes involved are still too high. Here, a miniaturized sensor based a coplanar Ground-Signal-Ground waveguide and SU-8 microfluidic network dedicated to characterize picoliter volumes is proposed. The set up description is given in Section 2. Experimental results and a validation with water/ethanol mixtures are presented in section III.

2. Set-Up Description

The miniaturized sensor is a coplanar Ground-Signal-Ground waveguide as shown in Figure 1 which behaves like a miniaturized open-ended-probe. The tapered coplanar line topology (gold lines deposited onto quartz substrate) is designed up to 10 GHz to achieve a 20 µm-width signal line associated with a 2.5 µm-gap. Electromagnetic simulations based on (Ansys/HFSS®) demonstrate insertion losses less than 2 dB up to 10 GHz. The interaction between the electric field and the liquid under test is achieved thanks to an SU-8 microfluidic channel placed on top of the sensor. The crosssection of the microfluidic channel is 50 µm per 50 µm and 50 µm high (Figure 1). The volume of sample that can be analyzed is equal to 125 picoliters.

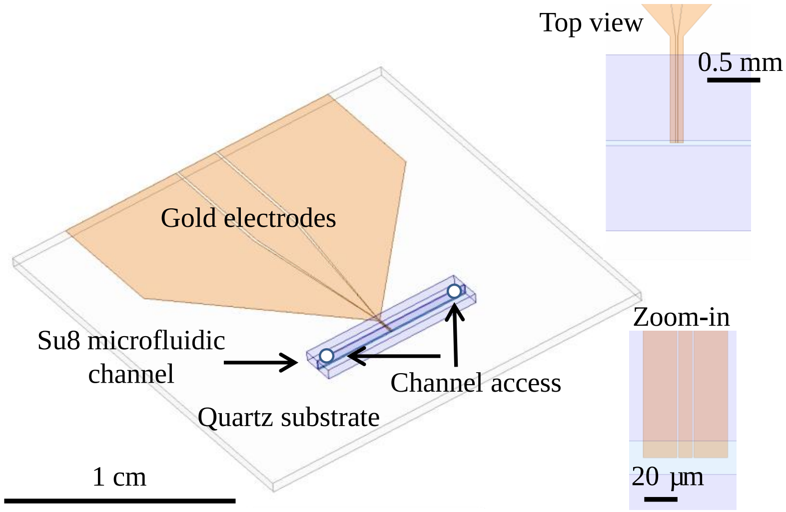

Figure 1. Schematic representation of the microwave/microfluidic sensor (HFSS picture), using gold electrodes in GSG (ground-Signal-Ground) configuration and SU8 microfluidic channel. The inset is a zoom-in.

An Anritsu Wiltron test fixture is used to connect the sensor to a Vector Network Analyzer and achieve reflection coefficient (S11) measurement in the frequency range from 30 MHz to 3 GHz. The Figure 2 shows the photography of the test bench using a VNA (E5061B) with the miniaturized sensor.

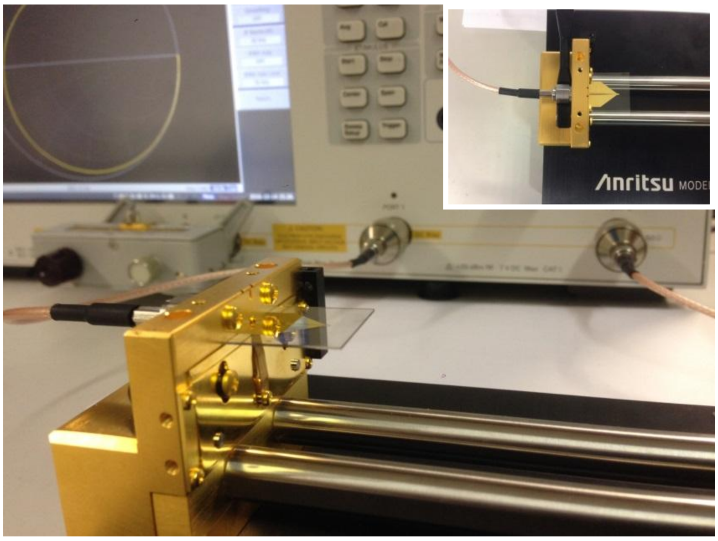

Figure 2. Photography of the test bench. The inset shows the top view.

3. RF Measurements

The fabrication of the miniaturized sensor is based on standard microtechnological processes. The device is fabricated using a 500 µm-thick quartz wafer. The structure is a coplanar line technology and consists of three gold metal lines deposited on the substrate. The full chip dimensions are: width (w) = 15 mm and length = 20 mm. Finally, the SU-8 microfluidic channel is deposited at the end of the coplanar guide (Figure 1).

To characterize the device, we investigate water/ethanol mixtures. The solutions were prepared by Ethanol (CARLO ERBA) and Millipore water. We measured ethanol/water mixtures at the molar fractions of ethanol, X_{EA} = 0.07, 0.17, 0.3, 0.7 and 1 at 20 °C in the frequency range 30 MHz to 3 GHz. These mixtures allow having solutions with a complex permittivity between 20 and 80 [12–16].

All measurements were obtained at room temperature from 30 MHz to 3 GHz (Figure 3). Each solution is measured using the average of 50 runs and input source is set to 0 dBm. The temperature of the liquids was also checked. As predicted, the difference in liquid properties can be clearly distinguished.

The analyte (volume= 125 pL) is placed in a SU-8 microfluidic channel. Figure 4 summarizes the reflection coefficient S11 measured for the different mixture at 1 GHz. We can note, that the module of reflection coefficient increased with the decreasing ethanol content. Thus, the imaginary part of S11, decreased with the increasing ethanol concentration. Results demonstrate that the miniaturized sensor characterizes accurately picoliter volumes with high sensitivity to the complex permittivity evolution.

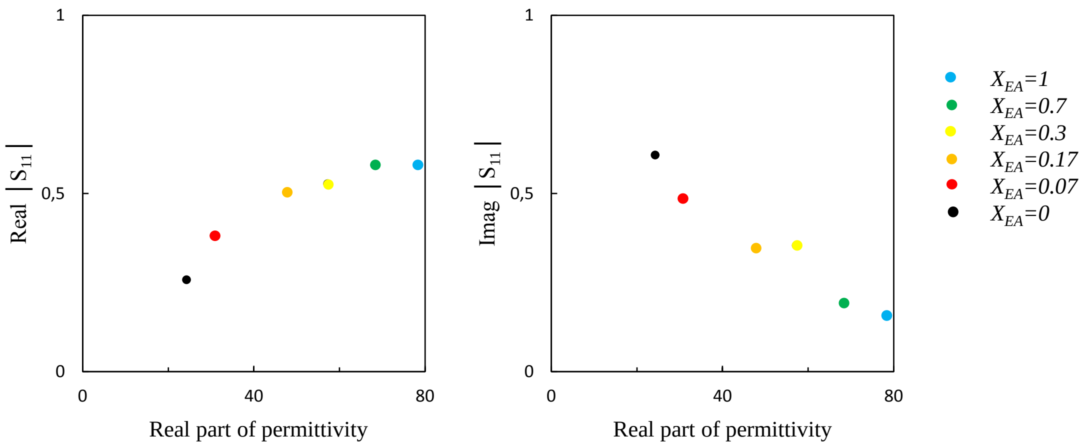

Figure 3. Experimental │S11│parameters of the sensor recorded at 1 GHz for ethanol/water mixtures retrieved at 20 °C and mole fractions XEA of ethanol.

4. Conclusions

In order to address the increasing need in characterization of picoliter liquids and biological cells, a miniaturized coplanar waveguide (CPW) sensor based on the interaction of a picoliter-range solution with the electromagnetic waves at gigahertz frequencies is developed. This sensor is designed using Electromagnetic simulations based on (Ansys/HFSS®). Experimental characterization of the device was carried out, highlighting its high sensitivity. The evolution of the real part and the imaginary part of the reflection coefficient S11 as a function of permittivity of different ethanol/water mixtures prove that the sensor is highly sensitive. These preliminary results show that the proposed instrumentation is a noninvasive solution to characterize picoliter volumes in a broadband range (0.03–3 GHz).

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Conflicts of Interest: The authors declare no conflict of interest.

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