RF Stretchable Sensor Using Flexible Substrate and Eutectic Gallium-Indium

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***Abstract* – In this paper, we proposed a radio frequency (RF) stretchable sensor using 3D printing, Ecoflex elastomer and eutectic gallium-indium (EGaIn). The proposed stretchable sensor is composed of two complementary split ring resonators (CSRRs). We can detect amount of stretching length from variation of resonant frequencies. Initially, two resonators are designed to resonate 2.03 GHz and 3.63 GHz. When we stretched the sensor, the resonant frequencies are shifted because the electrical length of resonators is changed.**

***Index Terms* — sensor, microfluidic channel, stretchable, CSRR, EGaIn, Ecoflex, 3D printing.**

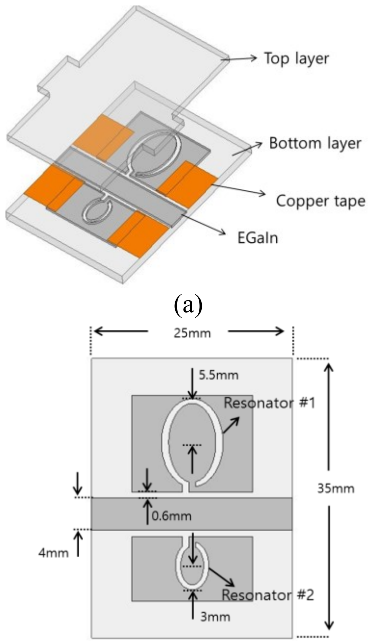
1. Introduction

In order to realize stretchable features, depositing thin-film metals on elastomers [1], Deep Reactive Ion Etching (DRIE) of silicon [2] and filling microfluidic channels with conducting materials [3] are typically used. A common way to fabricate microfluidic channels is sealing a substrate (e.g., glass or PDMS (polydimethylsiloxane)). It is realized by special method such as thermal evaporation, electro-deposition, e-beam evaporation, sputtering, patterning the metal (lithography), spin coating and ultraviolet exposure. Recently, microfluidic channels are built by laser ablation [4] and a three-dimensional (3D) printer [5].

In this paper, a radio frequency (RF) stretchable sensor with microfluidic channels is built by 3D printing, Ecoflex elastomer substrate and eutectic gallium-indium (EGaIn) liquid metal. Its resonant frequencies can be varied depending on strain level.

2. Stretchable Sensor Design

Fig. 1 (a) shows the proposed RF stretchable sensor design. It is composed of two layer Ecoflex 00-30 (Smooth-On, In. $\varepsilon_r = 2.8$) substrate. The bottom layer (thickness = 2mm) has CPW (coplanar waveguide) channel (thickness = 0.5mm) and different size of two complementary split ring resonators (CSRRs). The top layer (thickness = 1.5mm) is planar substrate without microfluidic channels. Fig. 1 (b) shows a geometry of the proposed CSRR. Two CSRRs are designed to resonate at 2.03 GHz and 3.63 GHz. We can detect stretched length from independent variation of two resonant frequencies. Microfluidic channels are filled by EGaIn (Ga 68.5%, In 21.5%, Sn 10%).



(a)

(b)

Fig. 1. (a) Bird's eye view of the proposed stretchable sensor, (b) Layout of CSRR resonators.

3. Fabrication and Results

In order to demonstrate the designed RF stretchable sensor, we first fabricated the microfluidic channel frames using a 3D printer (Ultimaker2). Next, we mixed the Ecoflex silicone elastomer base and curing agent at a ratio of 1:1. After mixing, a vacuum chamber is used to remove air bubbles of mixed solution. The mixed solution was cured at a room temperature for four hours. In order to fabricate quickly, we can choose a curing temperature at 100℃ for one hour. Before curing, we poured uncured solution to microfluidic channel frame. A copper tape and SMA connector are attached to the cured substrate. The two Ecoflex layers are attached by uncured Ecoflex solution. Finally, microfluidic channels are filled by liquid metal (EGaIn) using a syringe.

Fig. 2 shows the picture of the fabricated stretchable sensor. Fig. 3 shows the simulated and measured results. The measured resonant frequencies are 2.03 GHz and 3.68

GHz without stretching it. As shown in Fig. 3, the measurement result is similar to the simulated result.

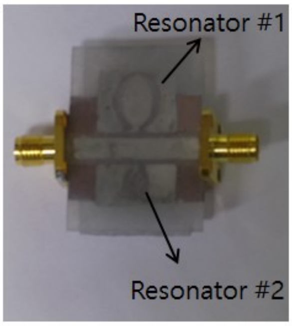


Fig. 2. Picture of the fabricated stretchable sensor.

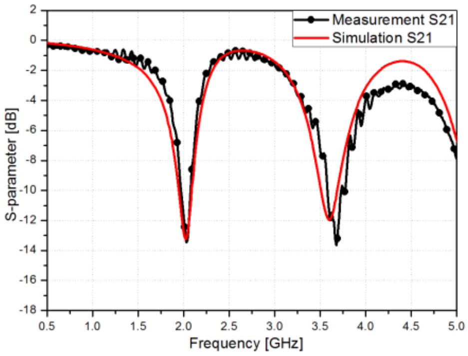


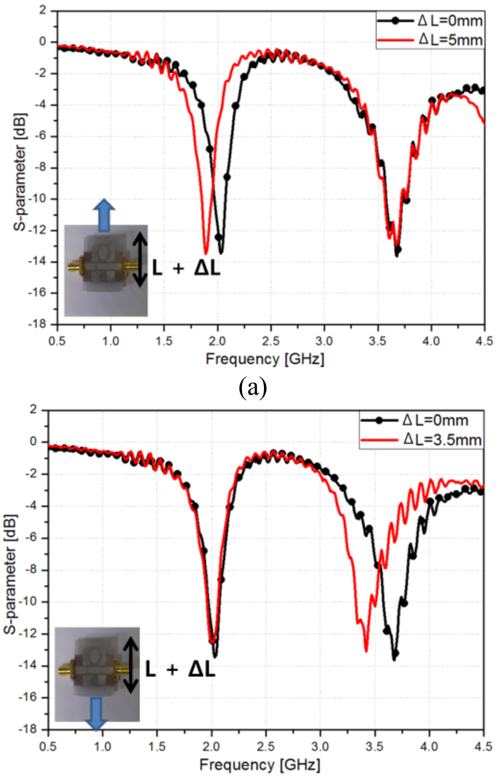
Fig. 3. Simulated and measured S-parameters of the proposed RF sensor.

We used a clamping fixture to stretch the sensor. L is initial length of the fabricated sensor. ΔL is stretched length.

As shown Fig. 4(a) and (b), the measured resonant frequencies are shifted 2.03 GHz to 1.89 GHz and 3.68 GHz to 3.40 GHz when resonator #1 and #2 are stretched from 0 mm to 3.5 mm and from 0 mm to 5mm, respectively. It can be demonstrated each resonator is working independently. Therefore, we can detect which resonator is stretched. When we increased ΔL to both direction of two resonator (+*y* and –*y* direction), every resonant frequencies are changed. When ΔL is increased, the resonant frequency is decreased because the electrical length of resonators is changed.

4. Conclusion

We proposed a novel RF stretchable sensor. The dielectric material and microfluidic channels are built using a 3D printer and Ecoflex. The conductive patterns are realized by injecting EGaIn into the microfluidic channels. Its performances are demonstrated by detecting the variation of resonant frequencies at different stretched level of ΔL. It is observed from measurement results that the resonant frequencies are shifted 2.03 GHz to 1.89 GHz and 3.68 GHz to 3.40 GHz when CSRR #1 and #2 are stretched from 0 mm to 3.5 mm and from 0 mm to 5mm, respectively. Therefore, the proposed RF sensor can be used as a strain sensor.



(a)

(b)

Fig. 4. Measured S-parameter results of the proposed stretchable sensor when (a) resonator #1 is stretched (ΔL=5 mm), (b) resonator #2 is stretched (ΔL=3.5 mm)

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