An Improved Multifunctional Frequency Selective Surface based on Microfluidic Technology

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***Abstract* – A multifunctional reconfigurable frequency selective surface has been presented based on microfluidic technology. The proposed design comprises periodic arrays of microchannels engraved in the opposite sides of an elastomeric substrate. With the selective injection of a liquid metal alloy inside the fluidic channels, the structure exhibits multifunctional characteristics (all pass, low pass, and bandpass responses with polarization-selectivity). The geometry has the novelty of having independent control in reconfigurability among the multiple number of working states. The proposed design has also been fabricated using laser etching technique, and the prototype shows measured results in close resemblance with the simulated responses.**

***Index Terms* — Frequency selective surface (FSS), microfluidic technology, multifunctional, liquid metal alloy.**

1. Introduction

Since the last few years, active frequency selective surfaces (AFSSs) [1] are playing a significant role in the present high-performing electromagnetic (EM) applications, owing to their reconfigurable characteristics. Surface mount components (like PIN diodes, varactors) are often used to realize these multifunctional structures, but the designs suffer from high cost, and complicated biasing circuitries [2], [3]. Microfluidic technology has recently been developed to improve the characteristics of AFSSs, while resolving the above limitations [4]. Fluidic channels are being encased in an elastomeric substrate, through which a liquid metal (or metal alloy) can be selectively flown, thereby resulting switchable responses. Recently, a few switchable designs have been reported based on microfluidic technology [5], however the number of states are limited, and need to be further improved.

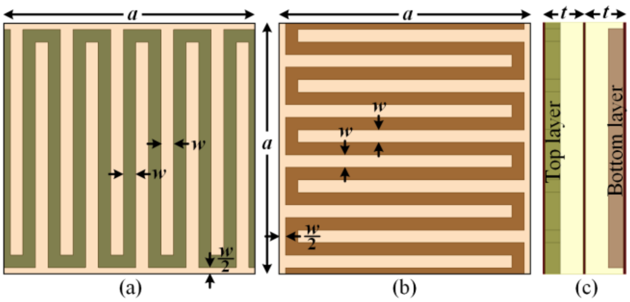

Fig. 1. Unit cell geometry of the proposed AFSS. (a) Top view of top layer, (b) top view of bottom layer, and (c) side view. Geometric dimensions are optimized as follows: $a = 10$ mm, $w = 0.5$ mm, and $t = 1$ mm.

In this paper, a microfluidically-reconfigured AFSS has been presented to exhibit multifunctional behavior aimed at various EM applications. The proposed design is made of an elastomeric substrate, top and bottom sides of which are engraved with microfluidic channels. A liquid metal alloy has been selectively injected in the channels to exhibit multiple responses (all pass, low pass, and bandpass) obtained from single geometry. Experimental verification of the fabricated prototype has confirmed the usefulness of the proposed design in various engineering applications.

2. Design and Analysis

Fig. 1 depicts the unit cell geometry of the proposed multifunctional AFSS. The design consists of meandered patterned microchannels engraved in the top and bottom layers of an elastomeric substrate, arranged in opposite polarization. Commercially available Polydimethylsiloxane (PDMS) substrate ($\varepsilon_r = 3$, and $tan\ \delta = 0.065$) is used as the intermediate dielectric, whereas Eutectic gallium indium (EGaIn) ($\sigma = 3.4 \times 10^6$ S/m) is used as the liquid metal alloy to flow inside the channels.

The proposed structure, while studied in Ansys HFSS software using periodic boundary conditions, exhibits multifunctional responses based on the flow of EGaIn inside the fluidic channels. When EGaIn is absent from both (top and bottom) channels, the structure transmits incident EM wave for all polarizations, thus behaving as a dual-polarized allpass response, as shown in Fig. 2. When

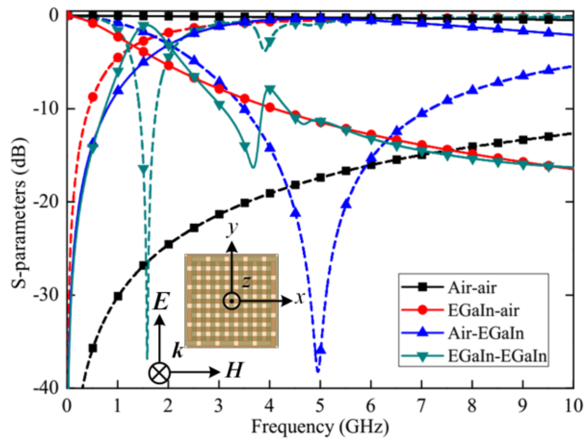

Fig. 2. Simulated scattering parameters of the proposed multifunctional FSS structure for different working states under y-polarized incident EM wave.

EGaIn is injected in the top layer only, the design exhibits a low pass response for vertical (*y*-) polarization and bandpass behavior under horizontal (*x*-) polarization, whereas the characteristics get reversed during the injection of liquid metal in the bottom layer (keeping the top layer empty). In the final state, when both channels are filled with EGaIn, the structure results in a bandpass response for both polarizations. This state has an additional advantage of exhibiting bandpass response at much lower frequency (1.58 GHz), thus giving rise to a miniaturized AFSS.

Since the structure exhibits identical responses for two states (when both channels are either filled with air or EGaIn) under vertical as well as horizontal polarizations, the design can be claimed as a polarization-insensitive for these two cases. The geometry also exhibits high angular stability upto 60° angle of incidence, as depicted in Fig. 3.

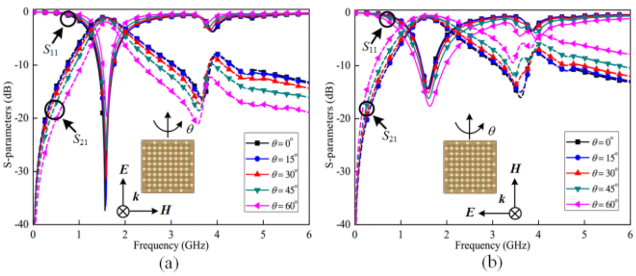

Fig. 3. Simulated scattering parameters of the proposed FSS structure (when both channels are filled with EGaIn) for various incident angles under (a) *y*- and (b) *x*-polarized incident wave. The solid and dotted lines represent the reflection and transmission coefficients, respectively.

3. Experimental Verification

To validate the proposed AFSS, a prototype was fabricated using laser etching technique. Fluidic channels were engraved in the opposite sides of a PDMS substrate, through which liquid metal could be flown in a selective way. Fig. 4 illustrates the fabricated sample, before and after the injection of EGaIn.

The sample was measured using free space technique and found to follow the footprint of the simulated results in all the working states. Under vertical polarization, the prototype exhibits all pass, low pass, bandpass (at 5.16 GHz), and miniaturized bandpass (at 1.61 GHz), with controlled injection of EGaIn inside the channels, as illustrated in Fig. 5. Slight deviation between the measured and simulated results can be accounted to fabrication error.

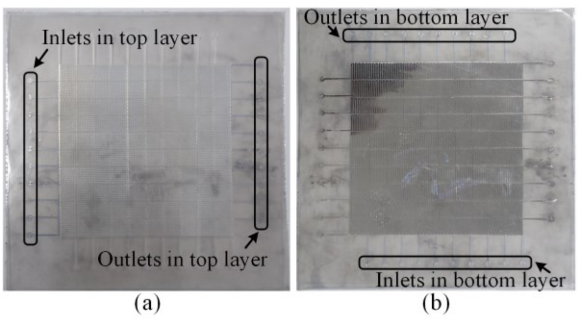

Fig. 4. Photographs of the fabricated prototype. (a) Before and (b) after the injection of EGaIn in both microchannels.

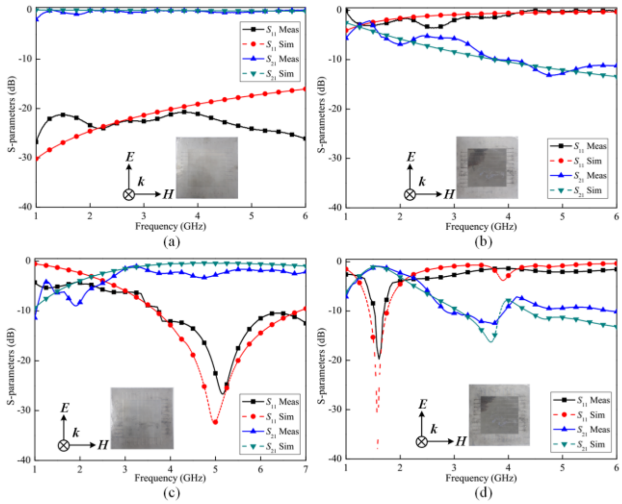

Fig. 5. Comparison of measured and simulated scattering parameters of the proposed FSS structure for different working states. (a) Both channels are empty, (b) top channel is filled with EGaIn, (c) bottom channel is filled with EGaIn, and (b) both channels are filled with EGaIn.

4. Conclusion

An improved reconfigurable FSS has been presented for multifunctional characteristics. The proposed design offers multiple number of working states for different conditions, unlike the earlier reported AFSSs. High angular stability, polarization-selectivity, as well as experimental verification have made the structure quite essential for EM applications.

Acknowledgment

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