



## **FACILE MICRO-FABRICATION TECHNIQUES FOR RAPID MANUFACTURING OF GALLIUM-BASED LIQUID METAL PASSIVE FREQUENCY SELECTIVE SURFACES**

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# 5-6<sup>TH</sup> Thermal and Fluids Engineering Conference (Virtual)

Dates: May 26-28, 2021



1

## Introduction

2

Design of Frequency Selective Surface

3

Frequency Selective Surface microfabrication by vacuum filling

4

Frequency Selective Surface microfabrication by SU-8 2075 stencil



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[Liquid Metal Alloy - \(Gallium, Indium, Tin\) : United Nuclear , Scientific Equipment & Supplies](#) (Last Accessed: 04/15/2021)

Gallium-based liquid metals:

- High flexibility
- High stretchability
- High electrical conductivity ( $3.4 \times 10^6$  S/m at 20° C)
- High thermal conductivity (39 W/m K at 368 K)
- Non-toxic



[The Advent of the Flexible Electronics Market \(kymc.com\)](#) (Last Accessed: 04/15/2021)

Smart material devices

- Flexible interconnection
- Flexible electrode
- Wearable and reconfigurable electronics



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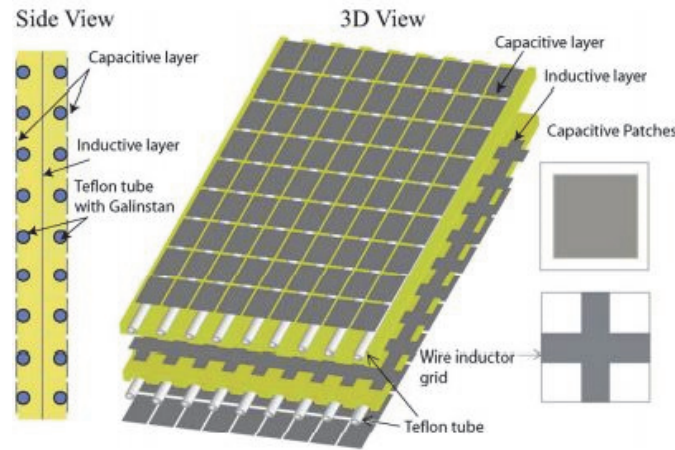
TFEC-2020-36592





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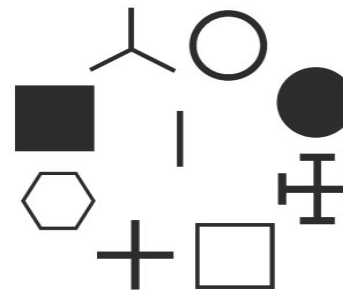
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Li, Meng, Bin Yu, and Nader Behdad. "Liquid-tunable frequency selective surfaces." *IEEE Microwave and wireless components letters* 20.8 (2010): 423-425.

Rigid FSS

What are these dots doing on the glass surface of the microwave oven?



FSS elements used

Bayatpur, Farhad. *Metamaterial-Inspired Frequency-Selective Surfaces*. Diss. 2009.





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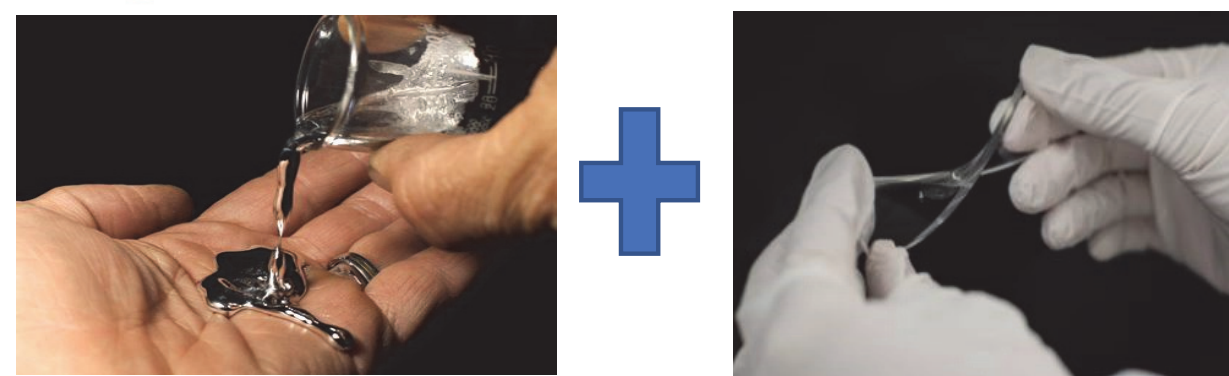
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Frequency Selective Surface microfabrication by SU-8 2075 stencil

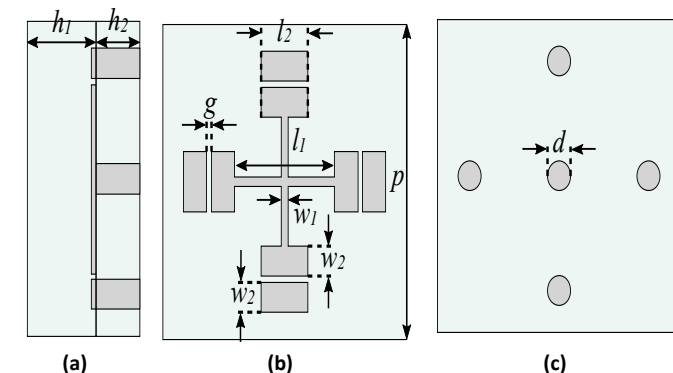


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[Materials for microfabrication – uFluidix](#)  
(Last Accessed: 04/15/2021)



Liquid metal band-stop FSS unit cell in PDMS:  
(a) side view ( $h_1=2.95$  mm and  $h_2=1.9$  mm),  
(b) modified Jerusalem cross layer ( $l_1=4.3$  mm,  $w_1=0.3$  mm,  $l_2=2$  mm,  $w_2=1$  mm,  $g=0.2$  mm and  $p=10.5$  mm),  
(c) liquid metal filled hole array ( $d=1$  mm).

Mitra, Arkadeep, et al. "Liquid Metal-Based Flexible Band-Stop Frequency Selective Surface." *2021 IEEE 34th International Conference on Micro Electro Mechanical Systems (MEMS)*. IEEE, 2021. 978-1-6654-1912-3/21/\$31.00 ©2021 IEEE



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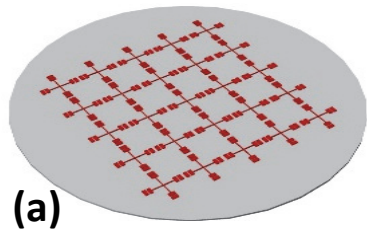
Frequency Selective Surface microfabrication by SU-8 2075 stencil



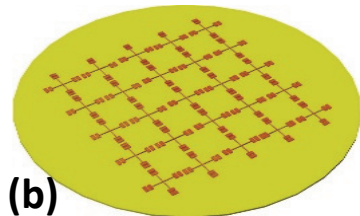


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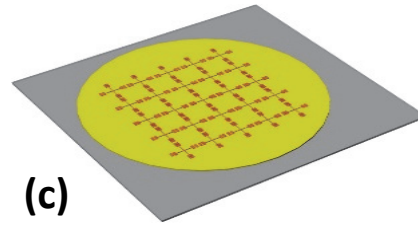
Dates: May 26-28, 2021



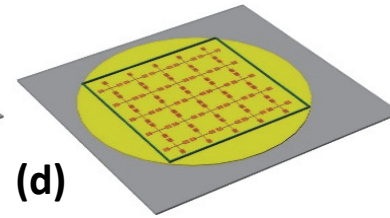
(a)



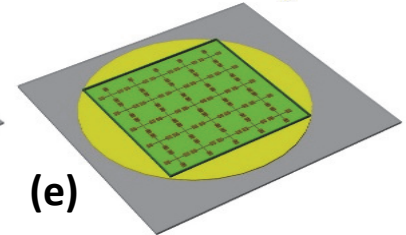
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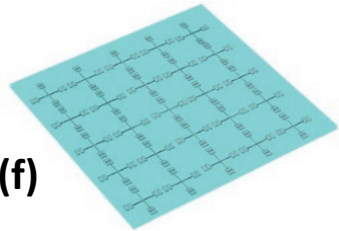
(c)



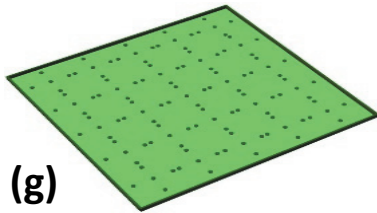
(d)



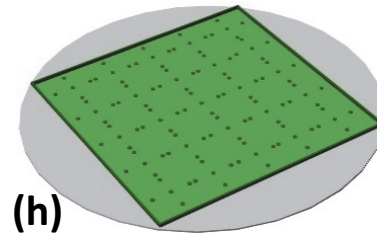
(e)



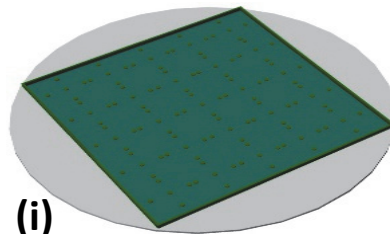
(f)



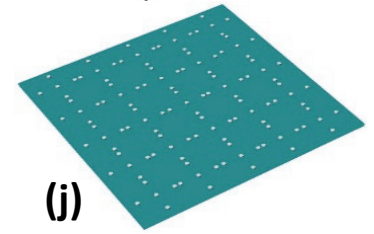
(g)



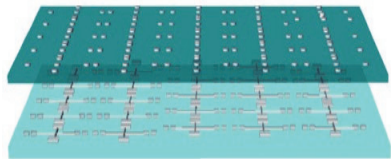
(h)



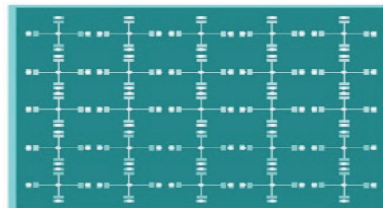
(i)



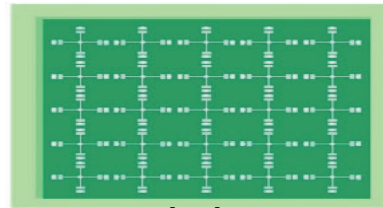
(j)



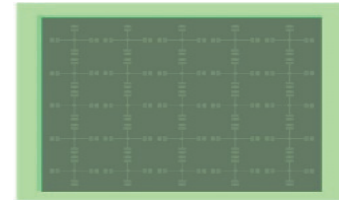
(k)



(l)



(m)



(n)

Fabrication sequence of FSS structures in ultra-low pressure: (a) Chromium hard mask on Si, (b) Teflon coated Si, (c) Si attached to scrap mask, (d) 3D borders attached to Si wafer, (e) PDMS poured on Si mold, (f) cured FSS-PDMS, (g) 3D pillar array mold, (h) pillar array mold attached to Si wafer, (i) PDMS poured on pillar array mold, (j) cured hole-array PDMS, (k) alignment of hole-array PDMS on FSS-PDMS, (l) bonded structure, (m) bonded structure placed in open top 3D container, (n) 3D container flooded with Galinstan. (Mitra, Arkadeep, et al. "Liquid Metal-Based Flexible Band-Stop Frequency Selective Surface." 2021 IEEE 34th International Conference on Micro Electro Mechanical Systems (MEMS). IEEE, 2021, 978-1-6654-1912-3/21/\$31.00 ©2021 IEEE)



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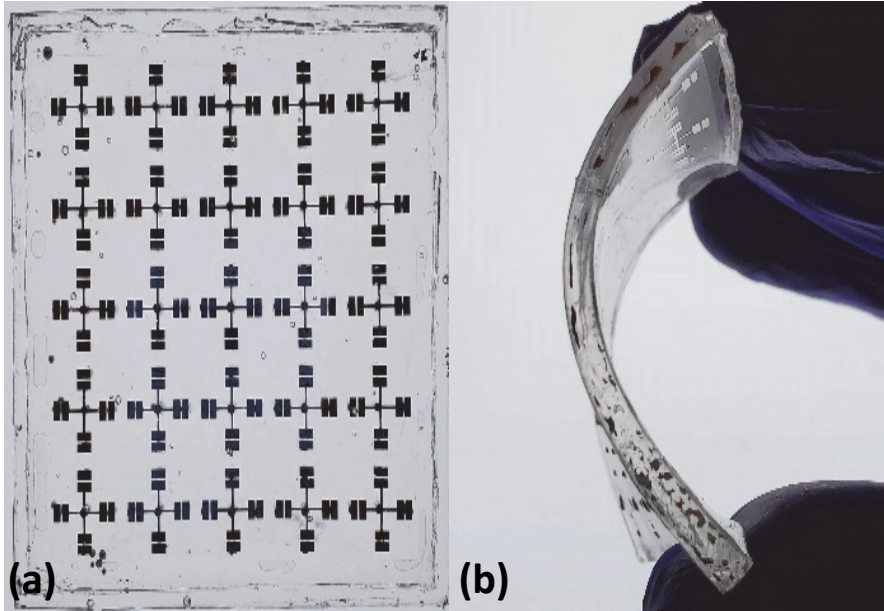
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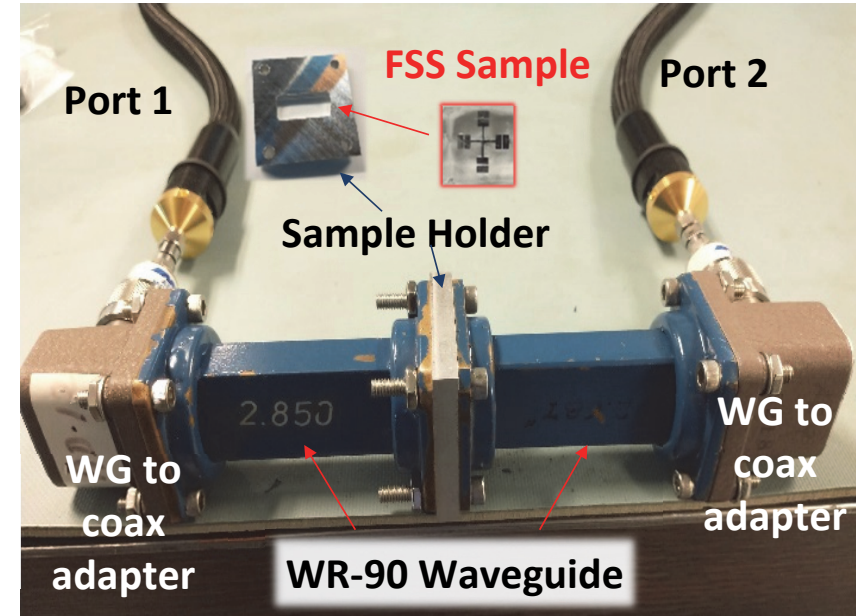


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*Liquid metal filled FSS structure by vacuum filling and post cleaning (a) top view, (b) side view\*\**



*Waveguide measurement setup\*\**

\*\* Mitra, Arkadeep, et al. "Liquid Metal-Based Flexible Band-Stop Frequency Selective Surface." *2021 IEEE 34<sup>th</sup> International Conference on Micro Electro Mechanical Systems (MEMS)*. IEEE, 2021, 978-1-6654-1912-3/21/\$31.00 ©2021 IEEE



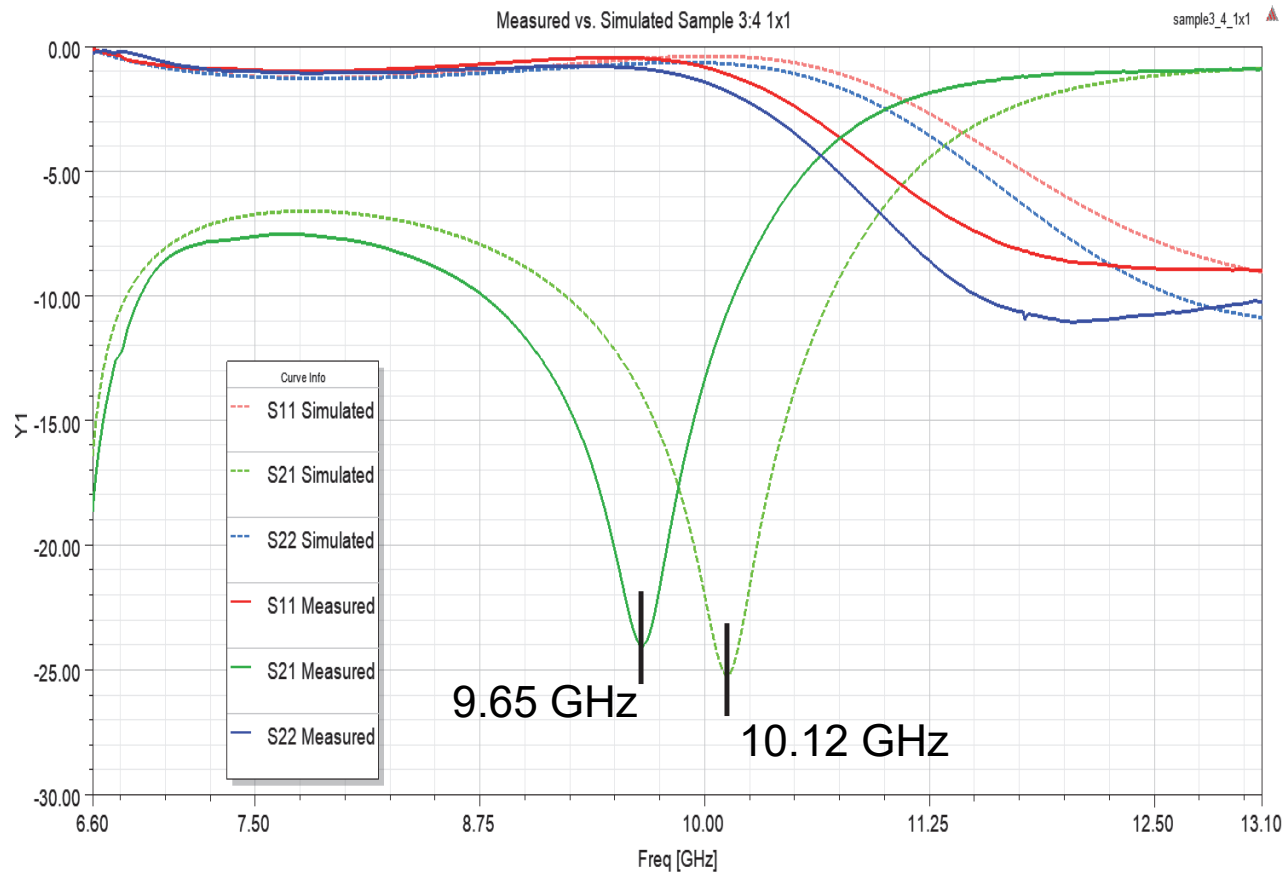
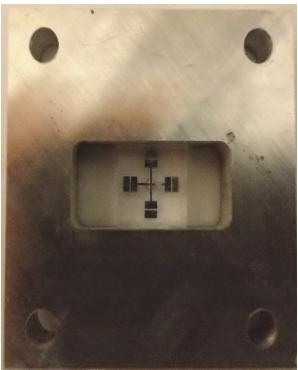


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Sample 3:4  
1x1: Keeping  
hole array  
PDMS intact



Total thickness: 4.7 mm,  
Hole array thickness:  
1.14 mm  
(FSS PDMS thickness:  
3.56mm)



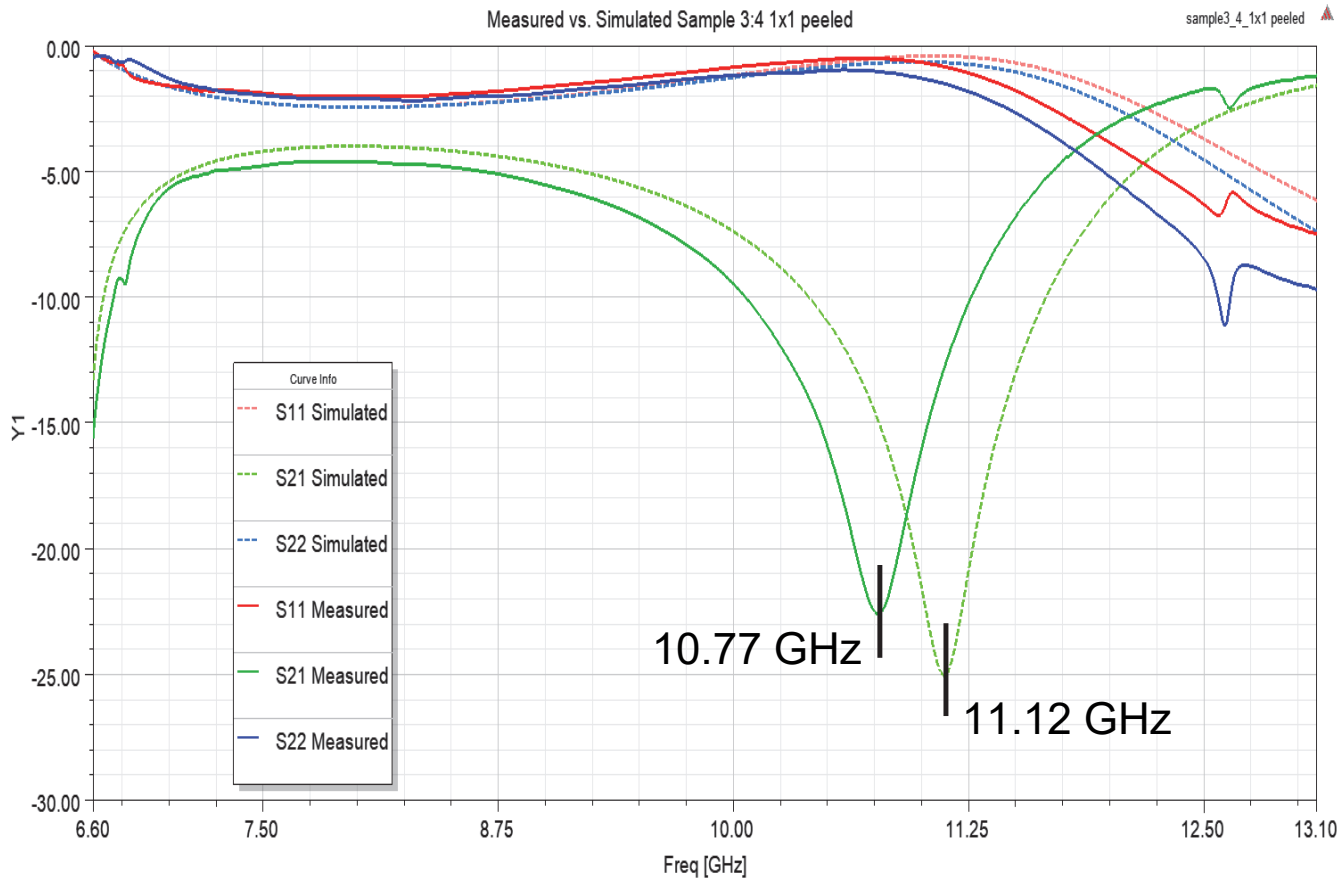
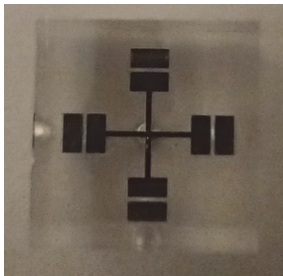


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Sample 3:4  
1x1 without  
PDMS hole  
array



Total thickness:  
2.97 mm

Resonant frequency is  
shifted up due to  
removal of hole array  
PDMS layer  
(decrease in  
capacitive loading)



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**(a)**

2  $\mu\text{m}$  thick thermally grown  $\text{SiO}_2$  on top of 4" n-type Si substrate

**(b)**

~70  $\mu\text{m}$  thick SU-8 2075 patterned and developed on top of  $\text{SiO}_2$

**(c)**

~70  $\mu\text{m}$  thick SU-8 2075 lift off by etching  $\text{SiO}_2$  using 7:1 BOE (~21 hours)



**(d)**

~70  $\mu\text{m}$  thick SU-8 2075 placed over partially cured PDMS (65° C for 25 mins: stencil placement, 101° C for 30 mins for complete curing)

**(e)**

Paasche Talon TG airbrush used for gallium-based liquid metal spraying (placed ~3-4 cm over sample, operated at 36 psi, spray time < 5 seconds)

**(f)**

SU-8 2075 layer removed leaving patterned gallium-based liquid metal on top of PDMS



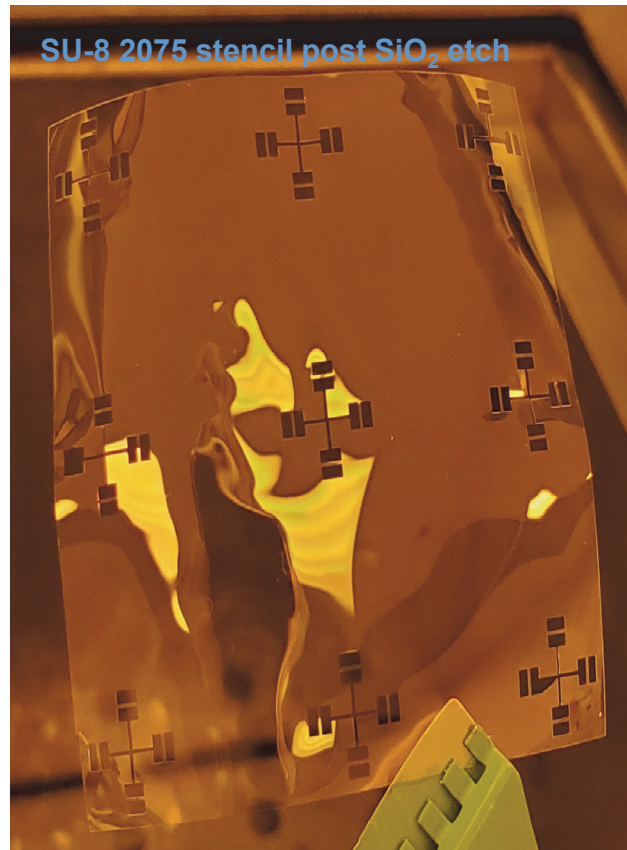


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SU-8 2075 stencil post  $\text{SiO}_2$  etch

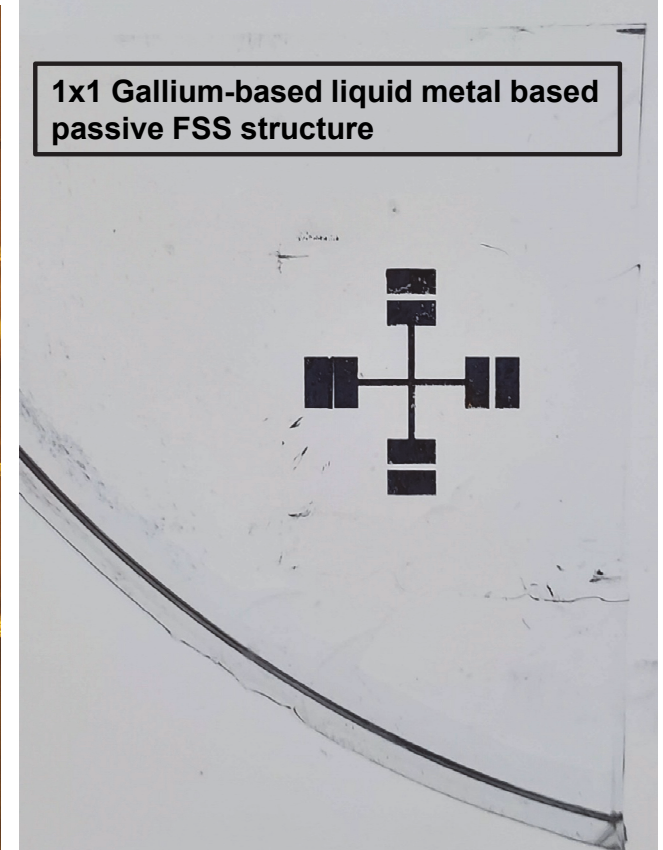


Fully cured PDMS (Approx. thickness: 1 mm)



70  $\mu\text{m}$  thick 1x1 FSS SU-8 2075 stencil

1x1 Gallium-based liquid metal based passive FSS structure





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- [3] Colleagues in University at Buffalo Microwave Lab,
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Please attend the Q&A session if you have any questions