

Th2E - 4

# Symmetrical Multiport mmWave Chalcogenide Phase-Change RF Switches

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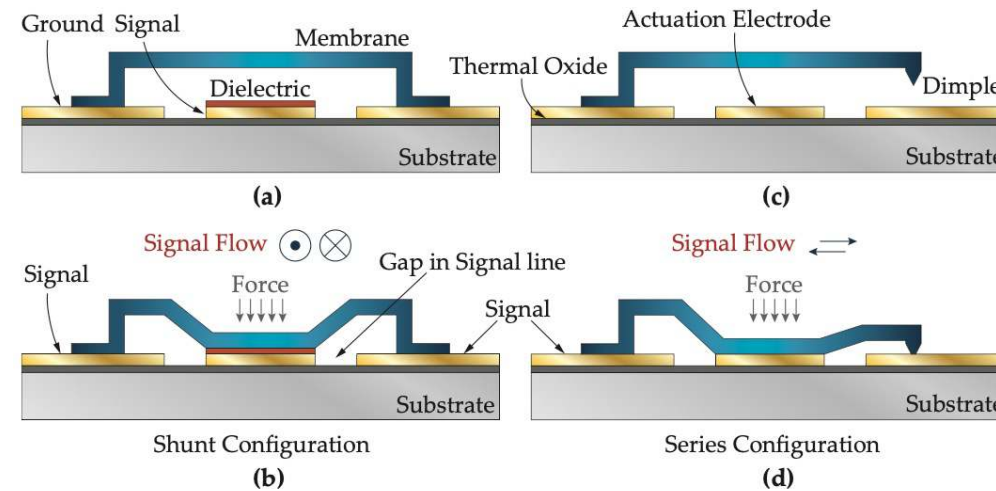
- Introduction
- Fabrication Process Flow
- RF PCM SPST Switches
- Simulation and Measurement Results
- SPDT, SP3T, SP8T and SP16T Switches
- Measured Performance and Optical Micrographs
- Summary

RF switches are some of the key components for any RF systems and circuits

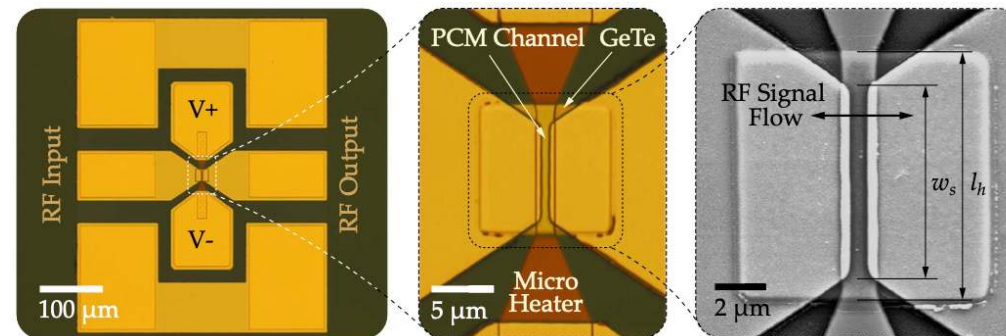
Waveguide



Coaxial

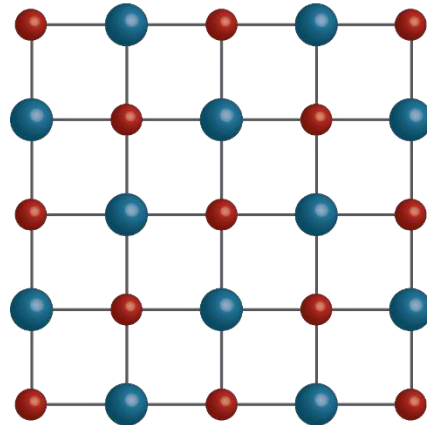


MEMS

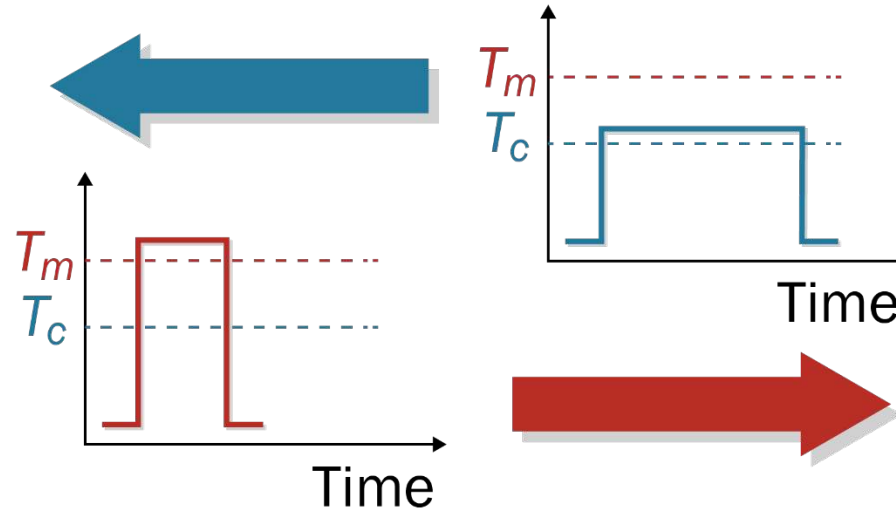


Phase-Change

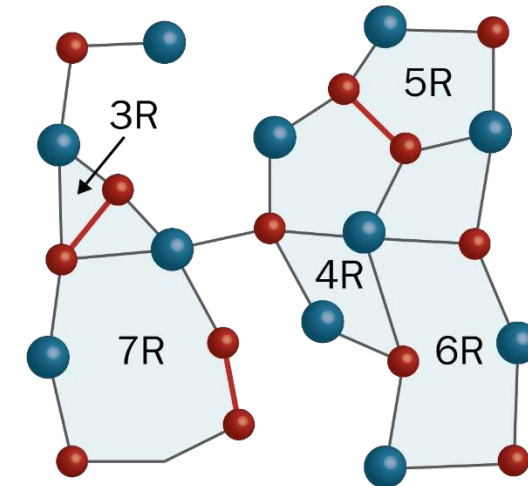
Crystalline State



● Ge or Se ● Te



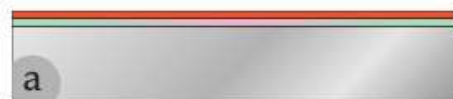
Amorphous State



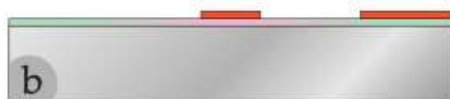
Transition between the amorphous (insulating) and the crystalline (conductive) states is accomplished by heating and cooling the PCM

| Parameters                | Semiconductor | MEMS                           | PCM                            |
|---------------------------|---------------|--------------------------------|--------------------------------|
| Frequency Range           | Microwave     | Microwave –<br>Millimeter Wave | Microwave –<br>Millimeter Wave |
| Insertion Loss            | High          | Low                            | Low                            |
| Isolation                 | Good          | Excellent                      | Very Good                      |
| Switching Speed           | Nanoseconds   | Microseconds                   | Microseconds                   |
| Linearity                 | Poor          | Excellent                      | Very Good                      |
| Monolithic<br>Integration | Good          | Poor                           | Good                           |
| Power Handling            | Very Low      | High                           | Medium                         |

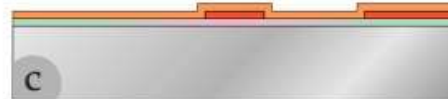




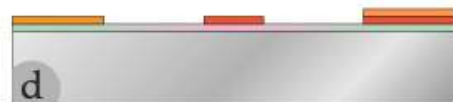
a Sputtering W (M0) on SiO<sub>2</sub>



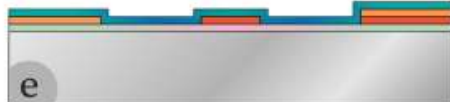
b Patterning M0 using RIE



c Sputtering Ag (M1)



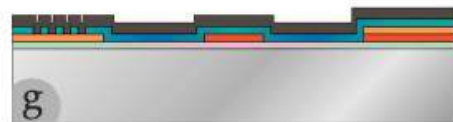
d Patterning M1 using RIE



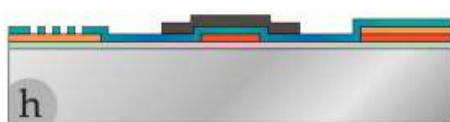
e Sputtering AlN (V0)



f Patterning V0 using RIE



g Sputtering GeTe (PC)



h Ion Milling PC



i Evaporating Cr/Au (M2)



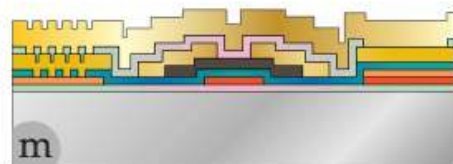
j Lift-off M2



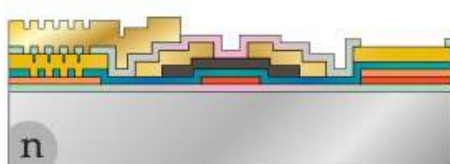
k PECVD SiO<sub>2</sub> (V1)



l Patterning V1 using RIE



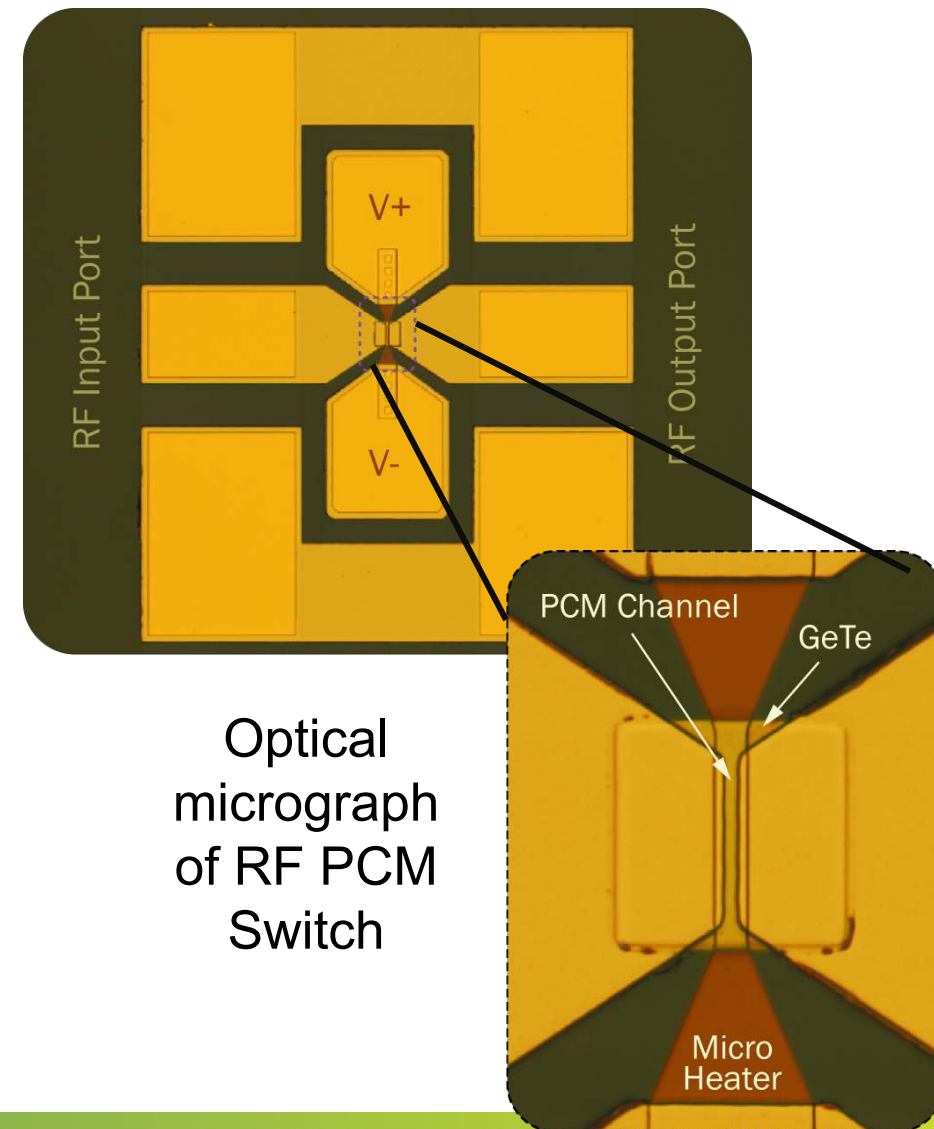
m Sputtering Ti/Au (M3)



n Lift-off M3

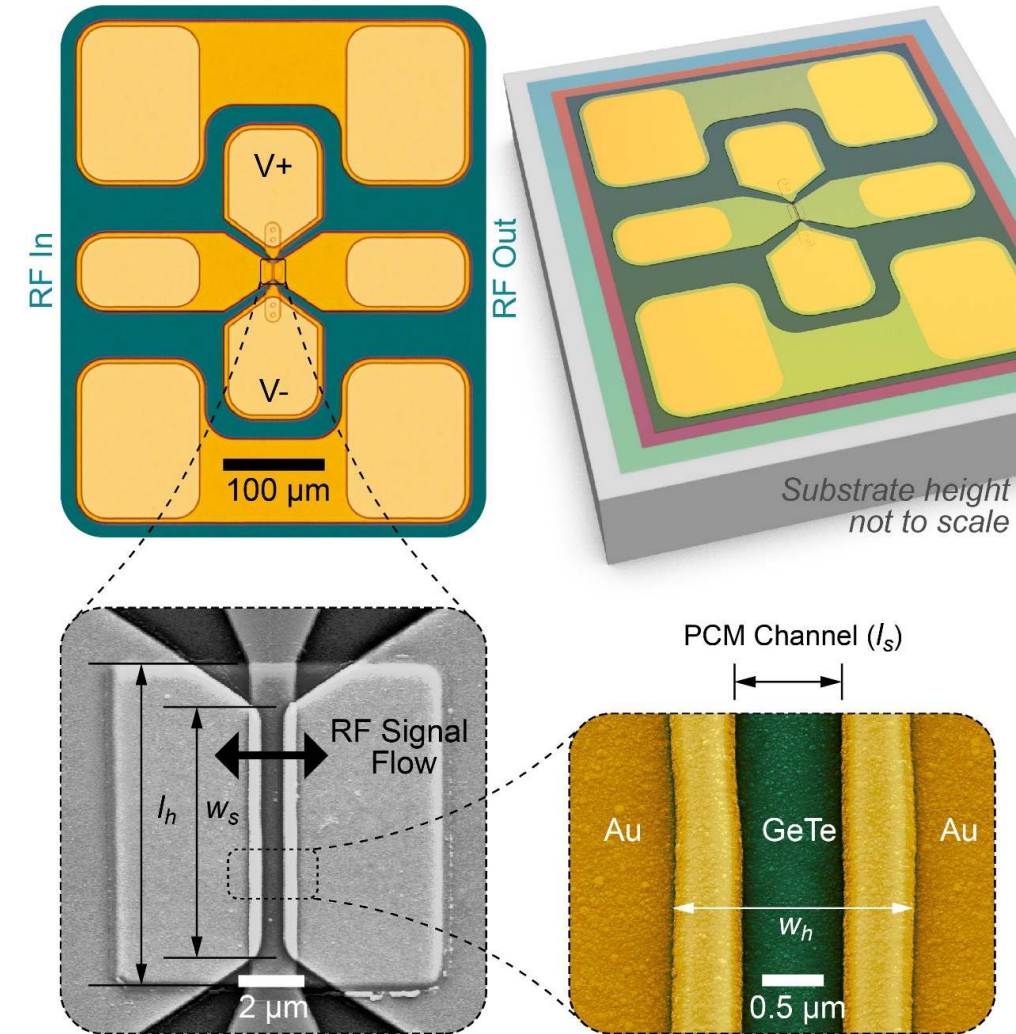


*\*Step coverage not to scale*

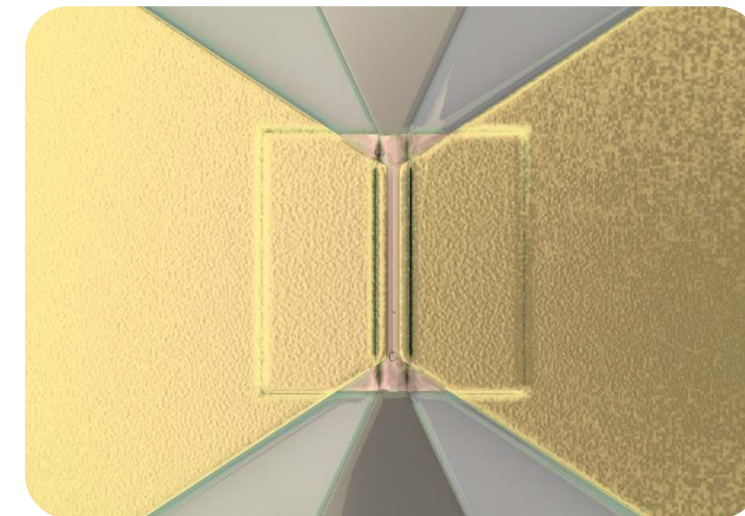
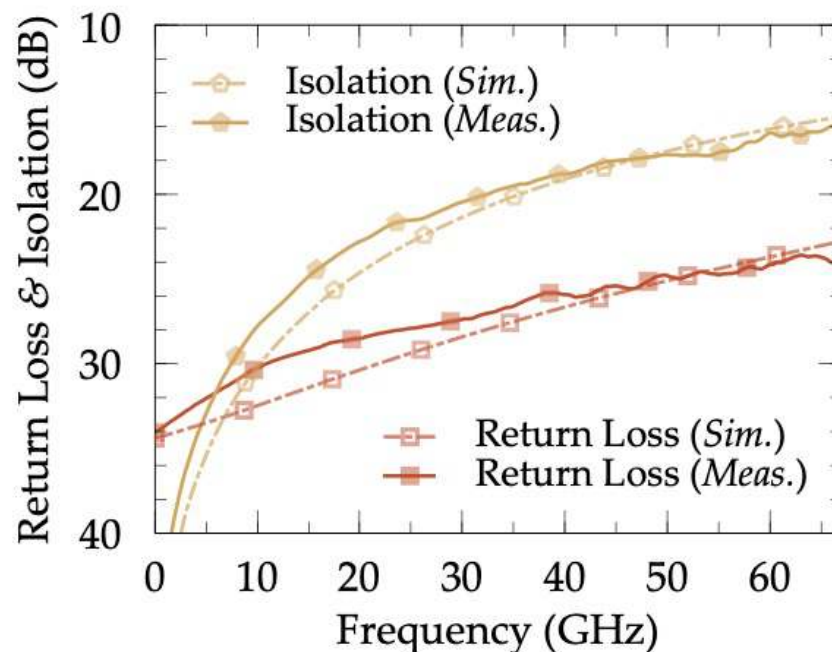
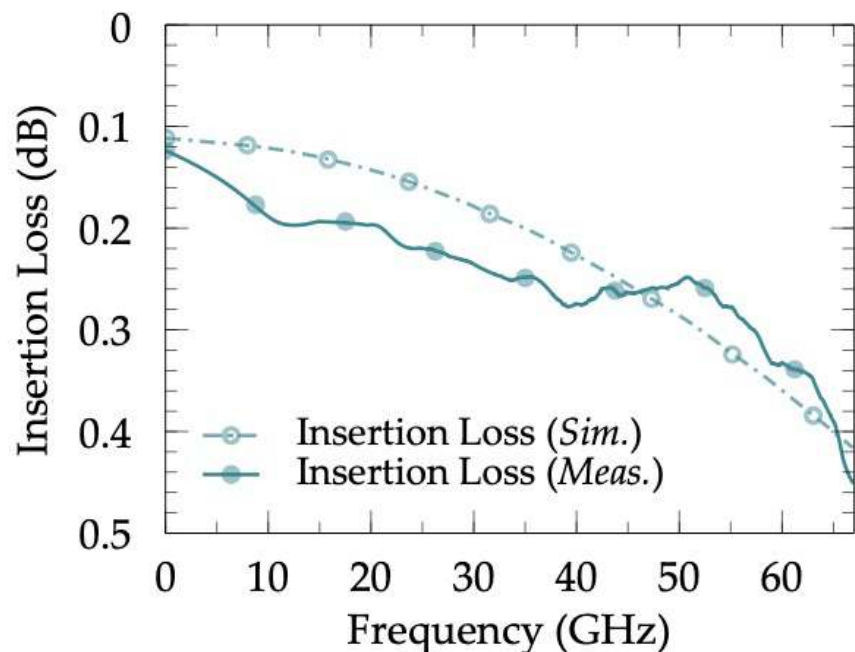


Optical  
micrograph  
of RF PCM  
Switch

- Ultra-wideband **DC-67 GHz** fully passivated compact PCM SPST switches
- Overall device size: 0.5 mm x 0.4 mm
- **SPST Core (for integration):  $30\text{ }\mu\text{m} \times 30\text{ }\mu\text{m}$**
- Loss < **0.45 dB**, Isolation > **17 dB**
- IP3 **41 dBm**, **35.5 dBm** CW power handling
- Up to **200 mA** static DC current handling
- Non-volatile max. switching time < **1.1  $\mu\text{s}$**
- Tested for > **1 million** reliable switch cycles





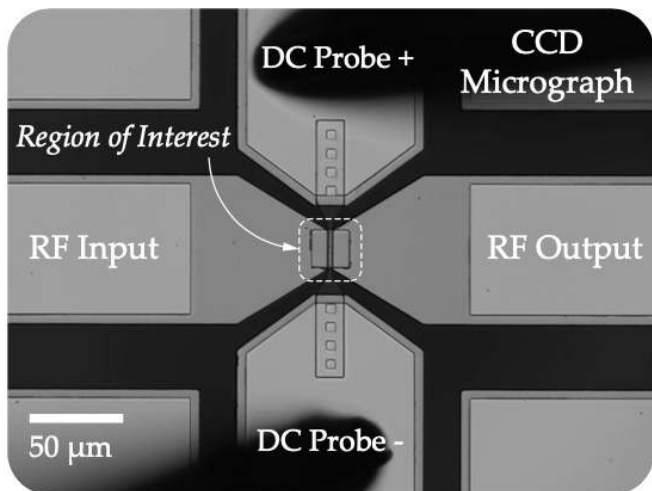


3D rendered view of  
RF PCM GeTe-Based  
SPST Switch

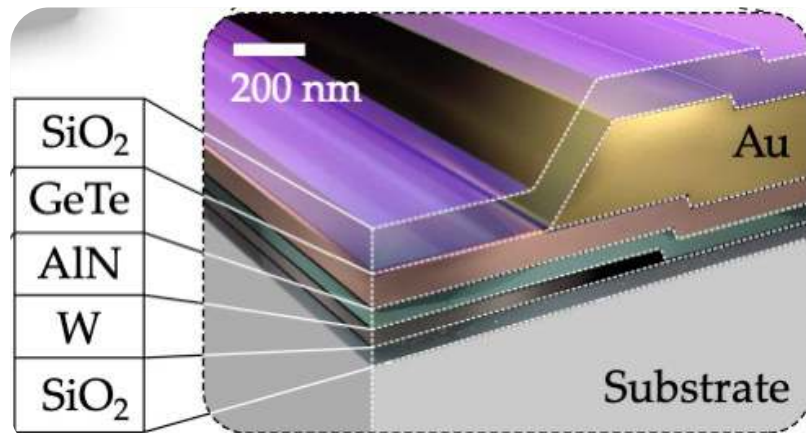
**T. Singh** and R. R. Mansour, "Characterization, optimization, and fabrication of phase change material germanium telluride based miniaturized DC–67 GHz RF switches," *IEEE Transactions on Microwave Theory and Techniques*, vol. 67, no. 8, pp. 3237–3250, Aug. 2019.

| $w_s$            | $l_s$             | $w_h$             | $l_h$            | $R_{on}$      | $R_{off}/R_{on}$ Ratio |
|------------------|-------------------|-------------------|------------------|---------------|------------------------|
| 10 $\mu\text{m}$ | 3 $\mu\text{m}$   | 2 $\mu\text{m}$   | 20 $\mu\text{m}$ | 4.9 $\Omega$  | $1.2 \times 10^4$      |
| 15 $\mu\text{m}$ | 3 $\mu\text{m}$   | 3 $\mu\text{m}$   | 25 $\mu\text{m}$ | 3.7 $\Omega$  | $1.6 \times 10^4$      |
| 15 $\mu\text{m}$ | 2 $\mu\text{m}$   | 3 $\mu\text{m}$   | 30 $\mu\text{m}$ | 2.4 $\Omega$  | $2.9 \times 10^4$      |
| 20 $\mu\text{m}$ | 2 $\mu\text{m}$   | 2 $\mu\text{m}$   | 35 $\mu\text{m}$ | 1.8 $\Omega$  | $3.9 \times 10^4$      |
| 20 $\mu\text{m}$ | 3 $\mu\text{m}$   | 3 $\mu\text{m}$   | 35 $\mu\text{m}$ | 2.3 $\Omega$  | $2.6 \times 10^4$      |
| 10 $\mu\text{m}$ | 1.2 $\mu\text{m}$ | 0.8 $\mu\text{m}$ | 20 $\mu\text{m}$ | 1.61 $\Omega$ | $4.35 \times 10^4$     |

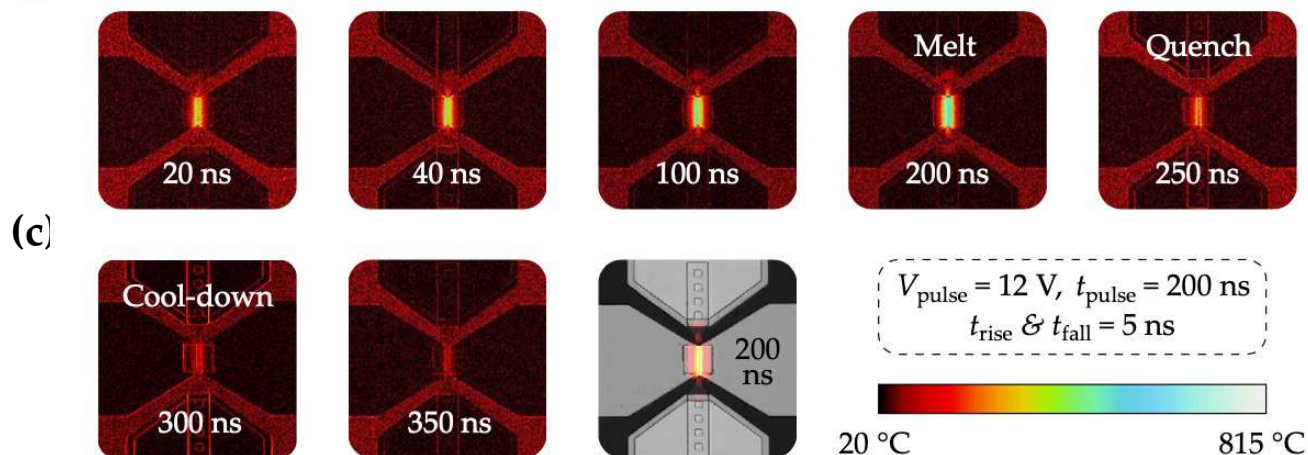




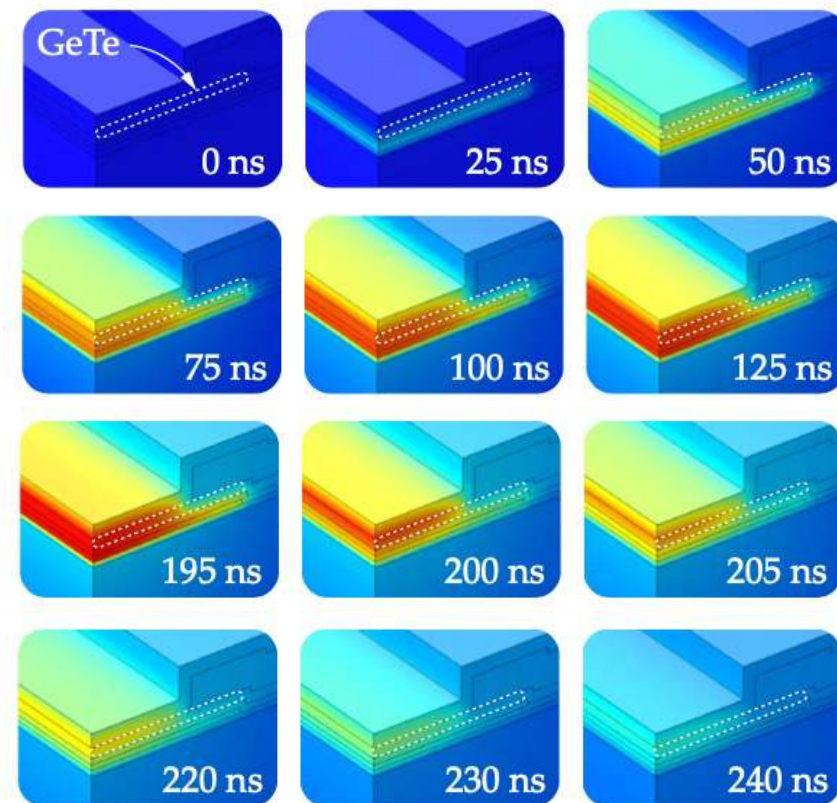
**(a)**



(b)



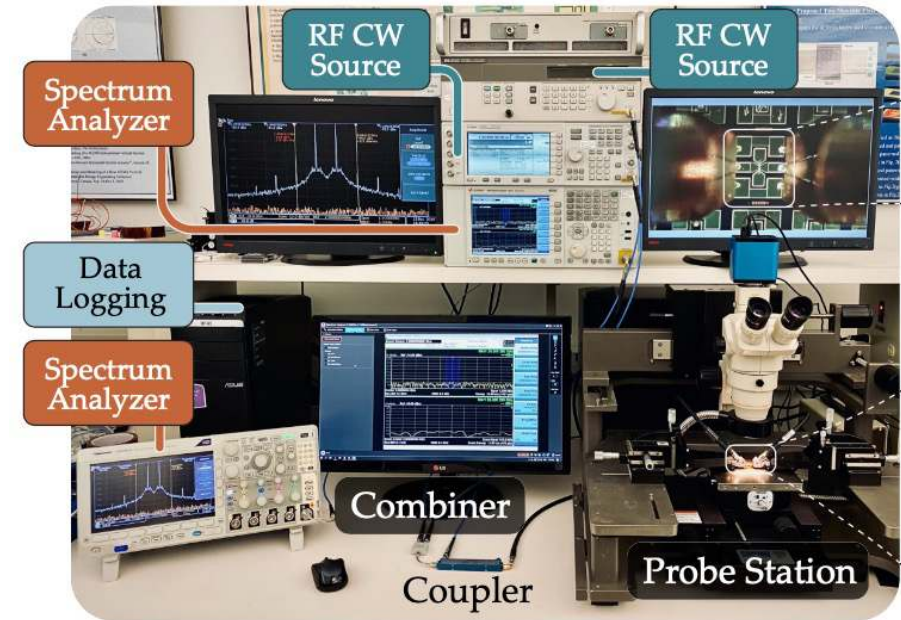
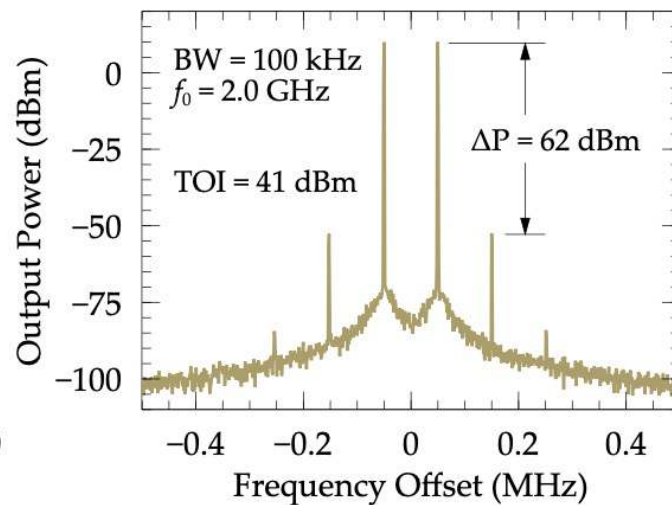
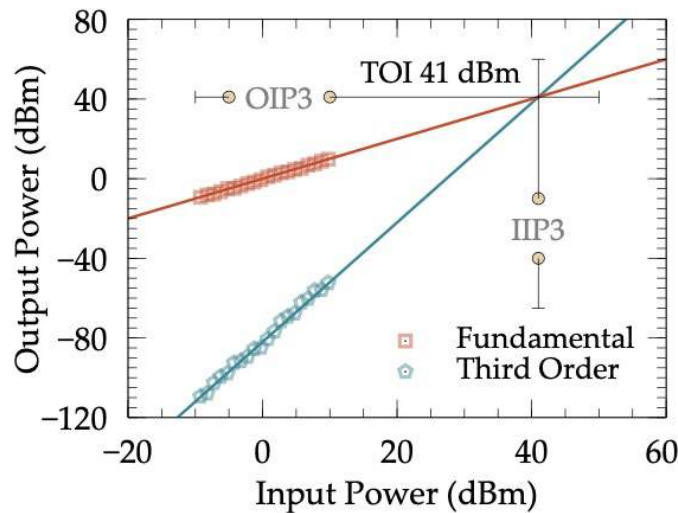
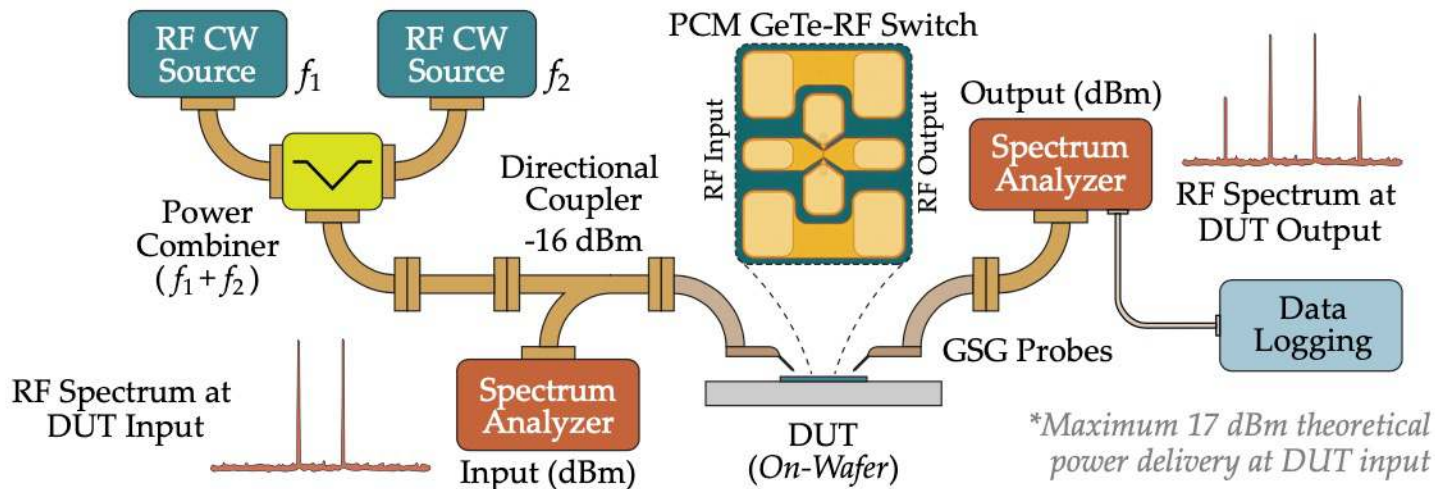
# FEM Transient Simulations



20 °C  750 °C

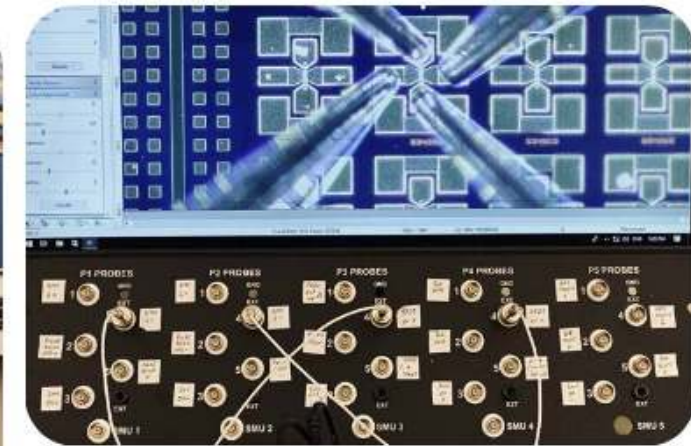
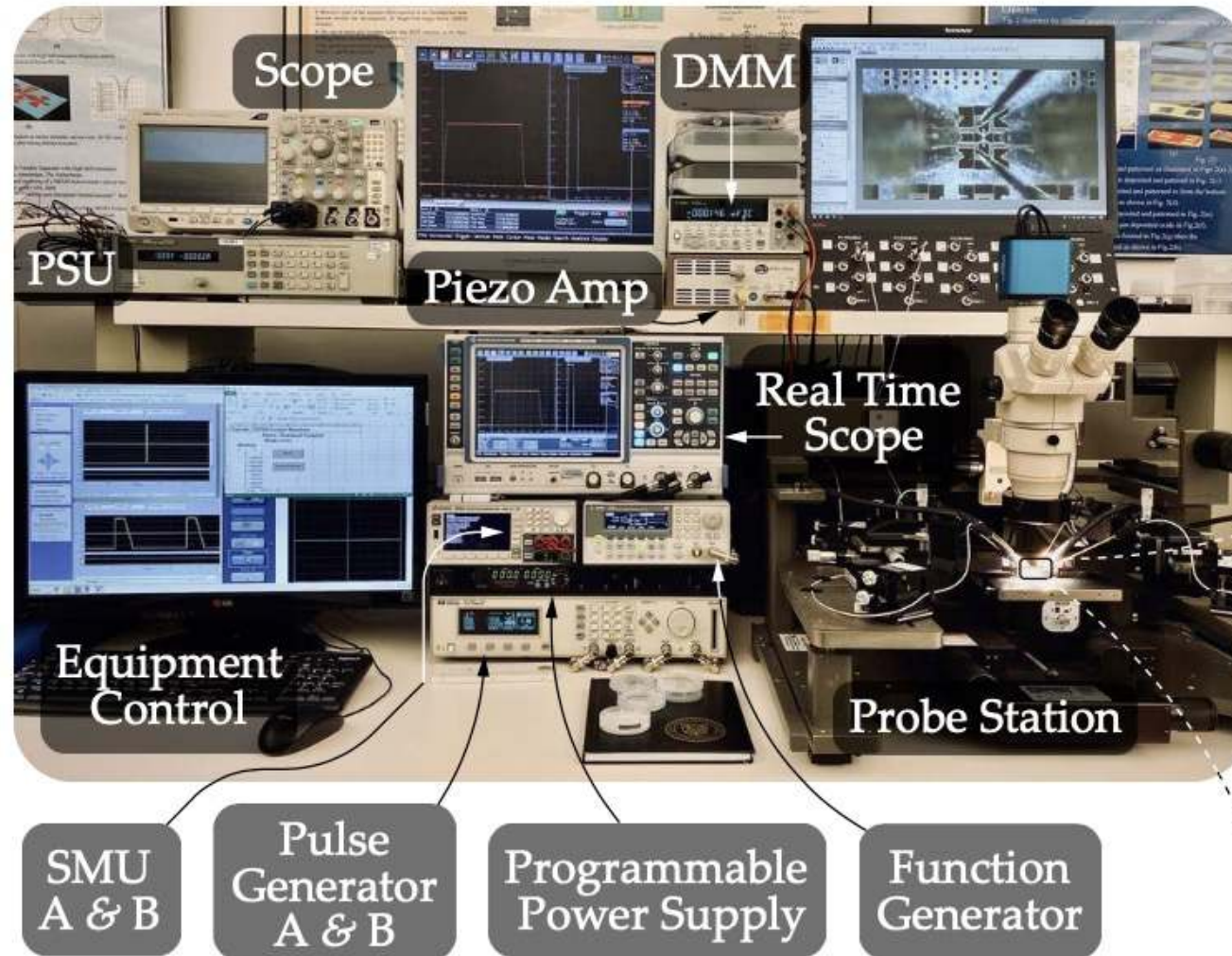
# Transient thermal imaging of RF PCM SPST switch for investigating thermal crosstalk





| Centre Frequency ( $f_0$ ) | Tone Separation (BW = $f_2 - f_1$ ) | Measured IP3 / TOI |
|----------------------------|-------------------------------------|--------------------|
| 2 GHz                      | 100 kHz                             | 41 dBm             |
| 2 GHz                      | 500 kHz                             | 42 dBm             |
| 2 GHz                      | 1 MHz                               | 45 dBm             |
| 3 GHz                      | 100 kHz                             | 42 dBm             |
| 3 GHz                      | 500 kHz                             | 42 dBm             |
| 3 GHz                      | 1 MHz                               | 44 dBm             |



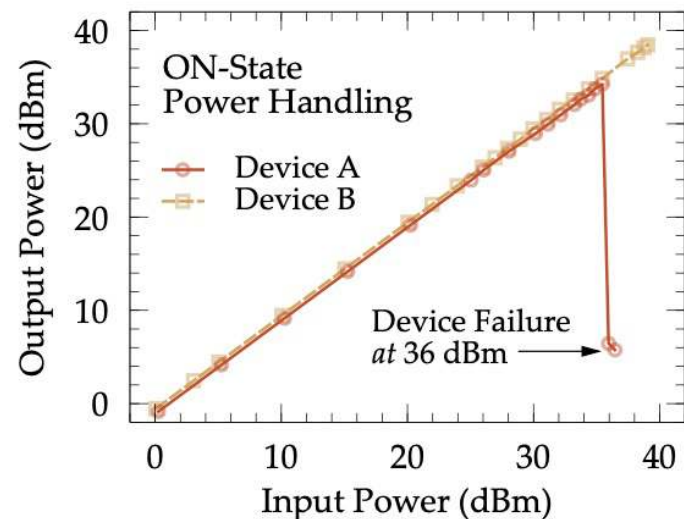


Modular Connection Matrix



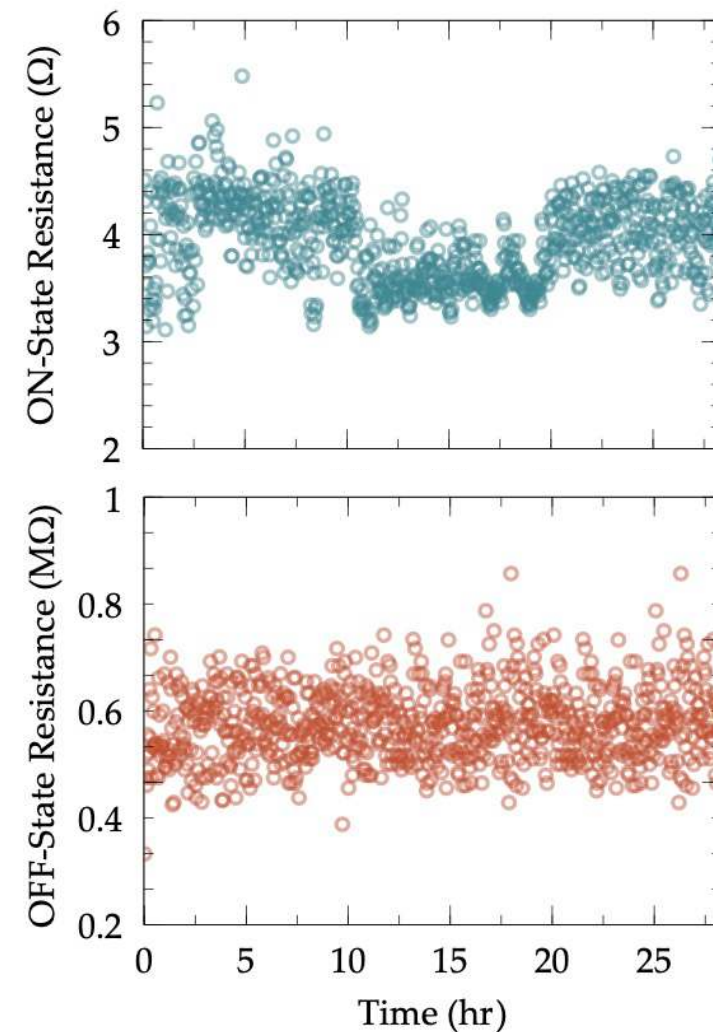
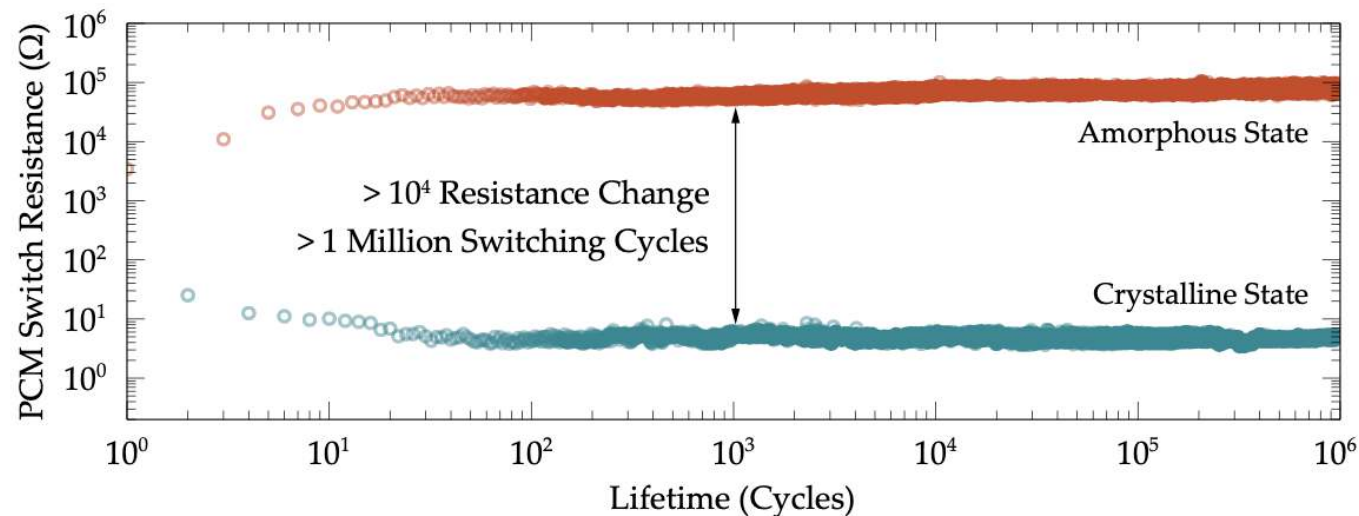
On-Wafer DC Testing

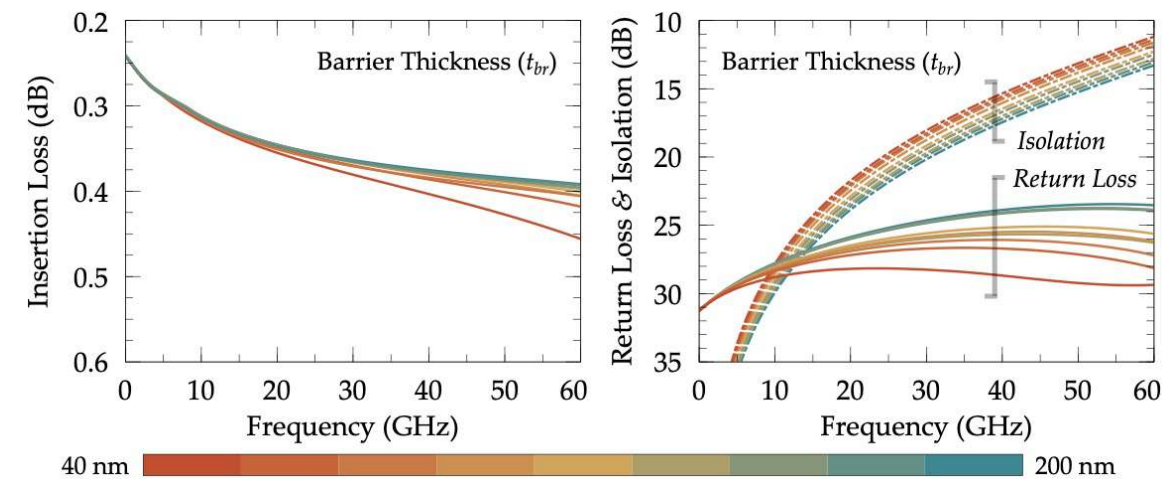
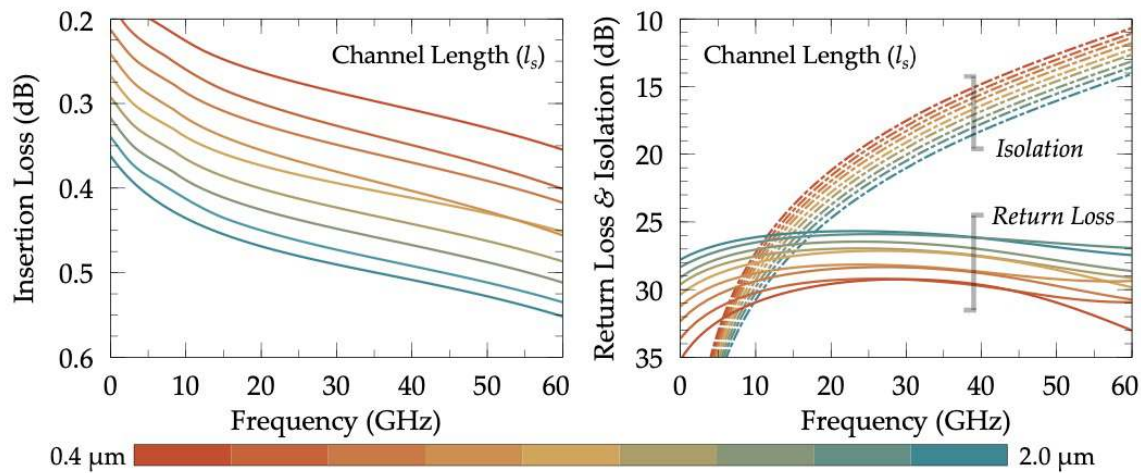
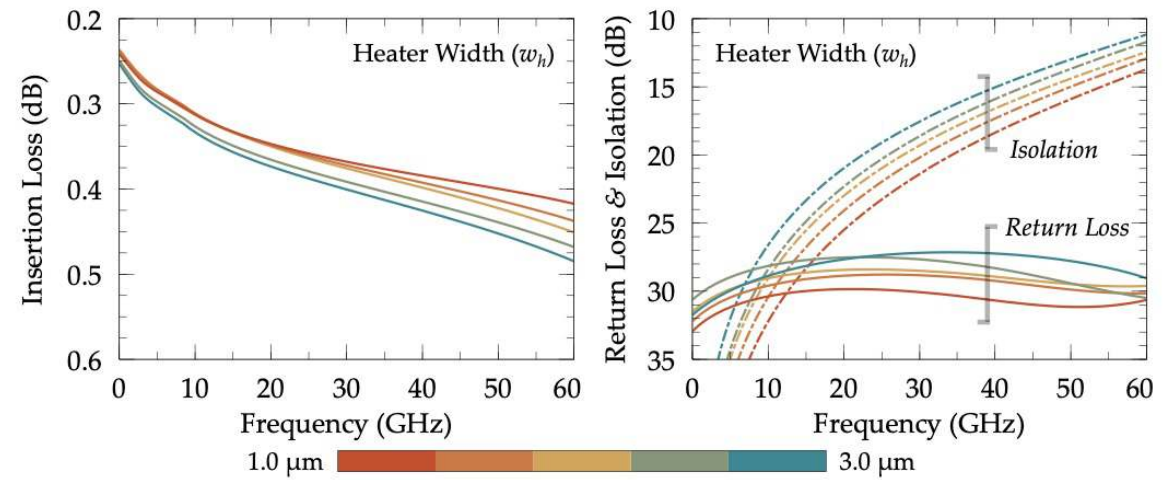
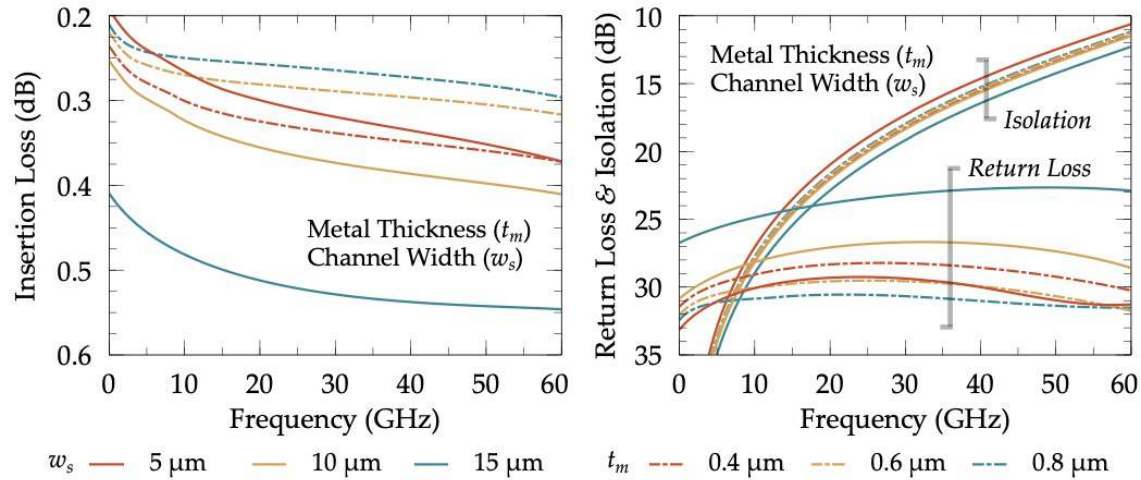




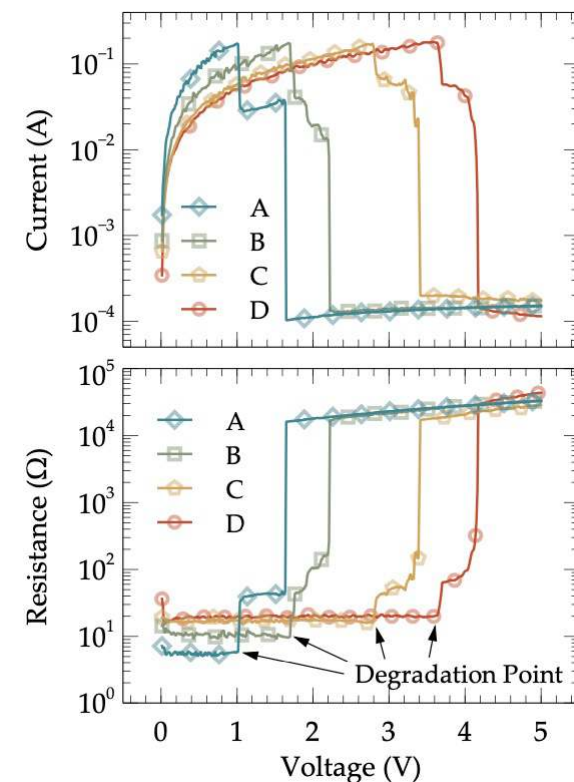
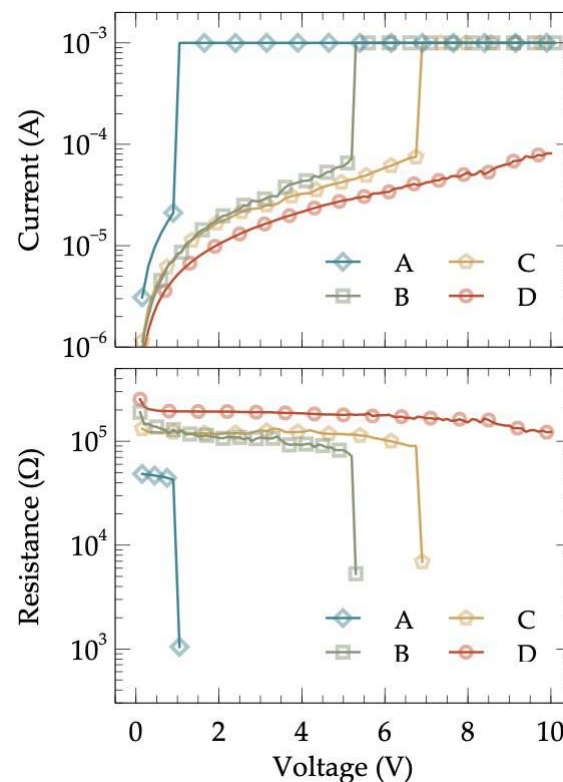
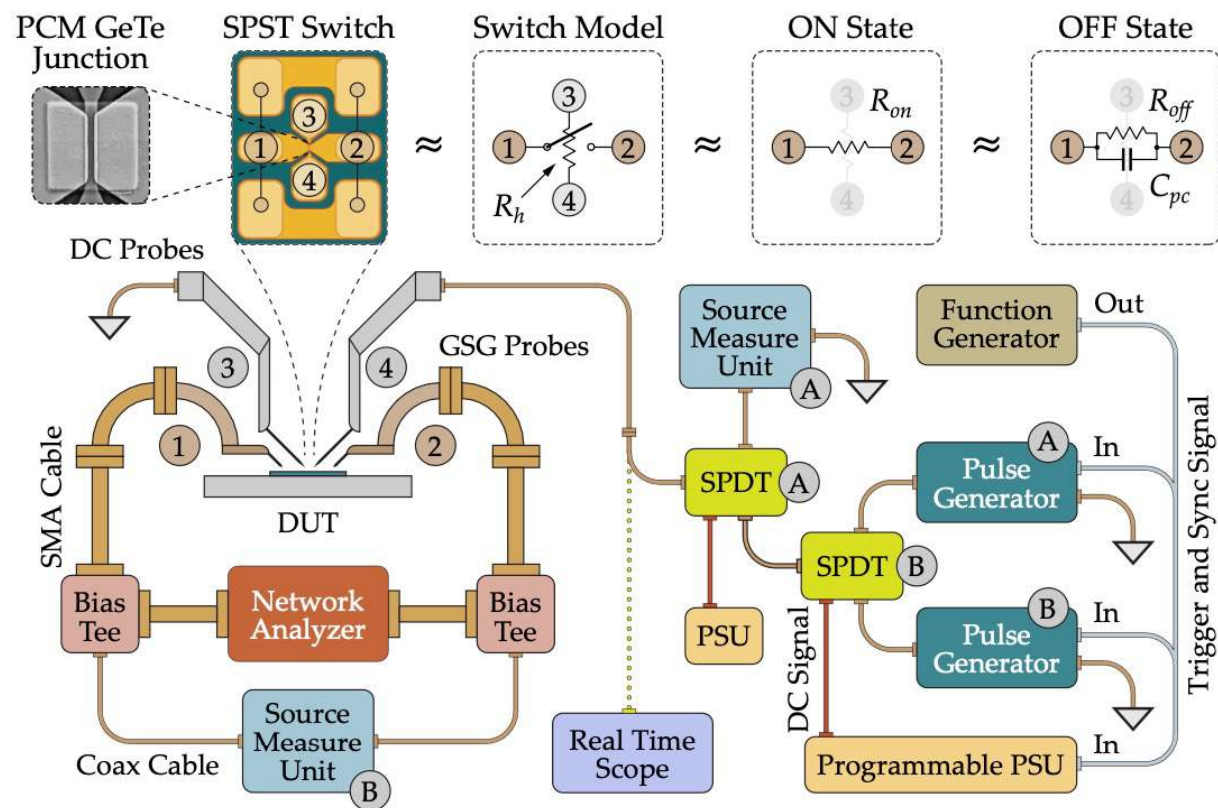
Device A: **35.5 dBm**  
(narrow PCM channel)

Device B: **> 40 dBm**  
(wide PCM channel)

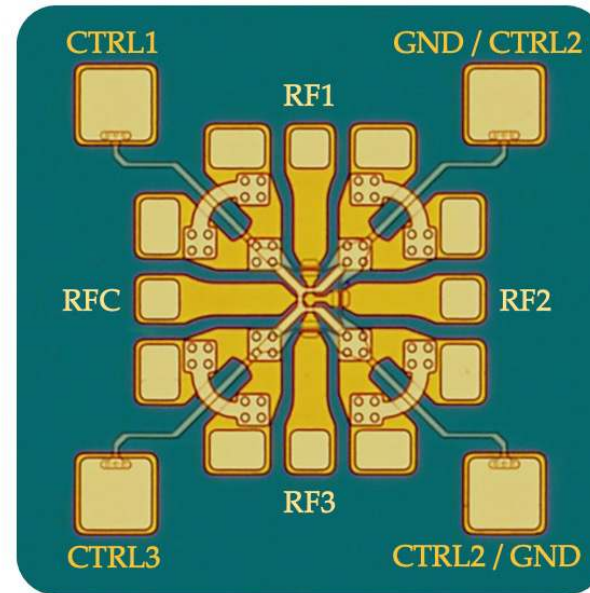
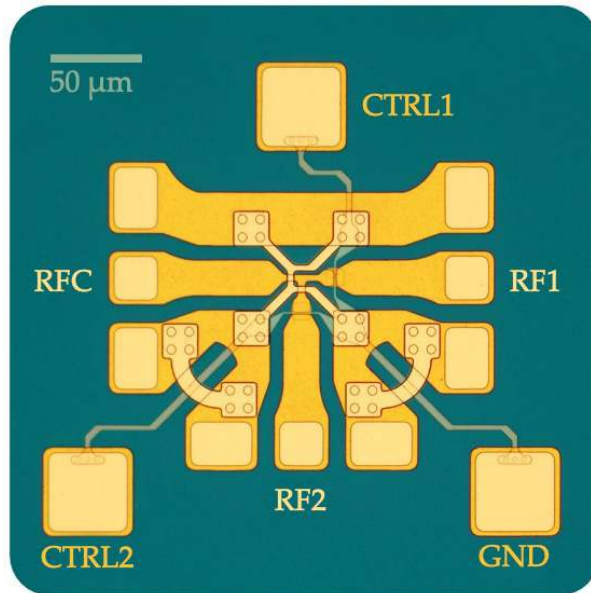




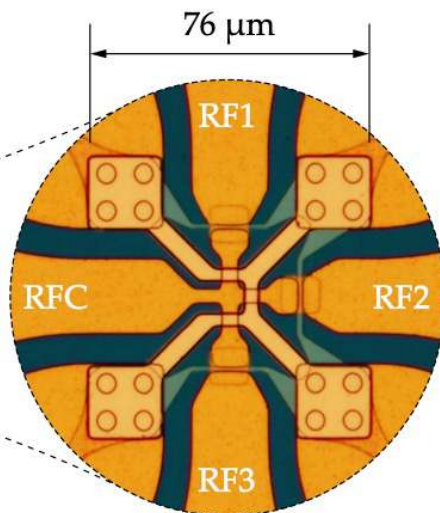
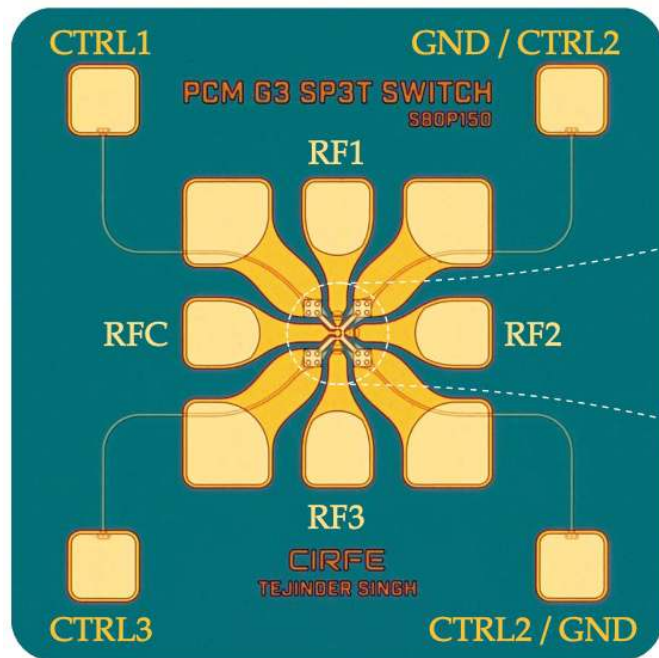




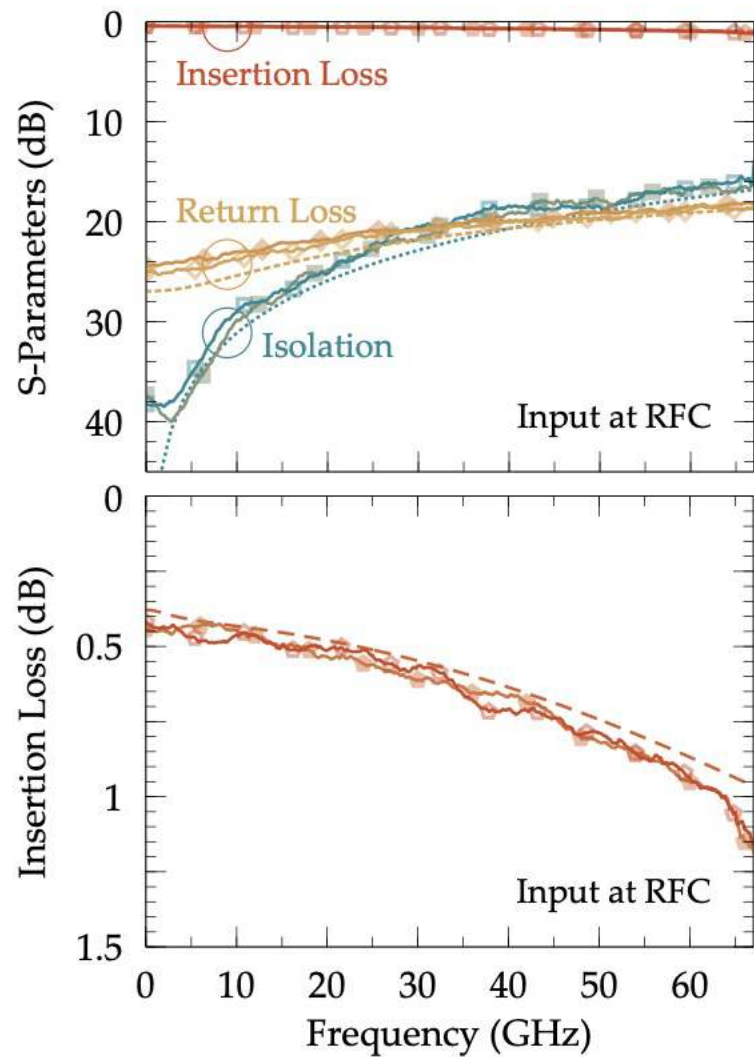




- Multi-port switches share the same junction dimensions as the SPST switches.
- RFC is the input port and RF1, RF2, and RF3 are output ports.
- Shared CTRL ports reduce the number of total DC ports.

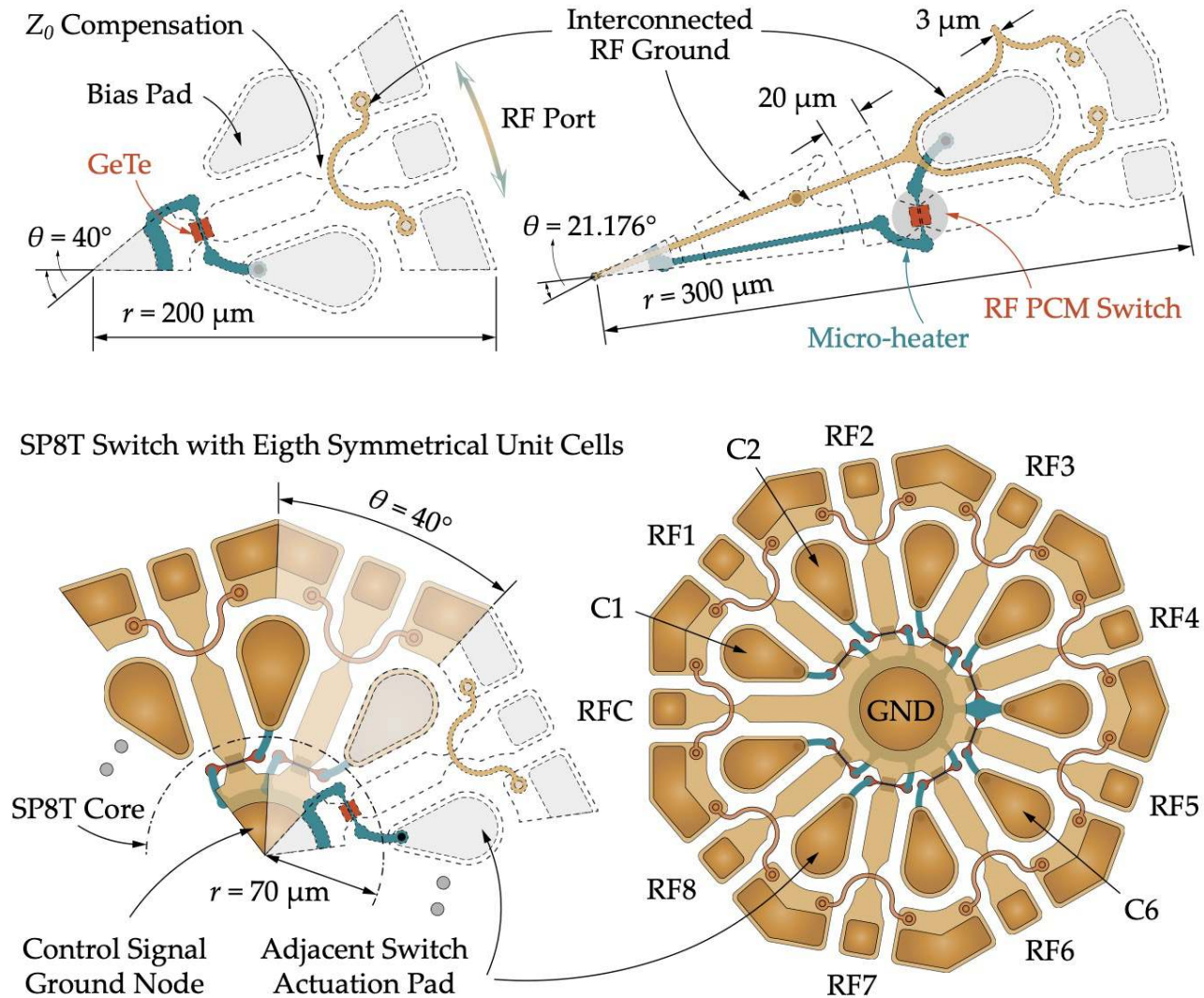


SP3T Core  
76  $\mu\text{m}$  x 76  $\mu\text{m}$

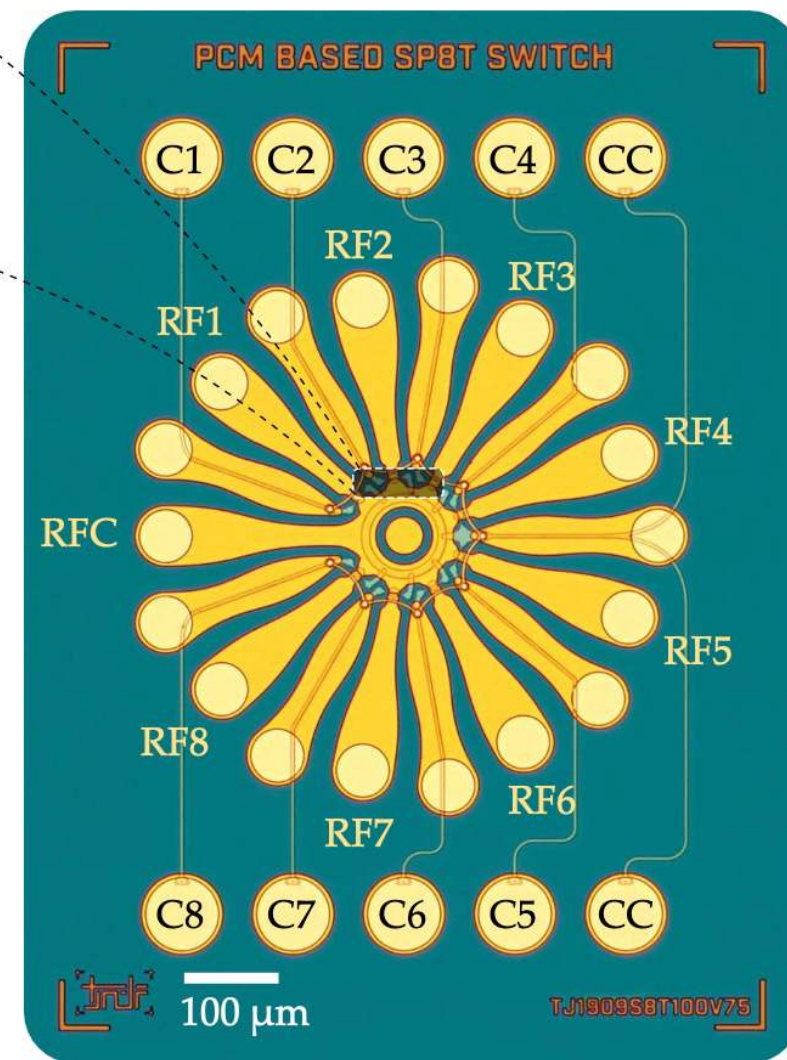
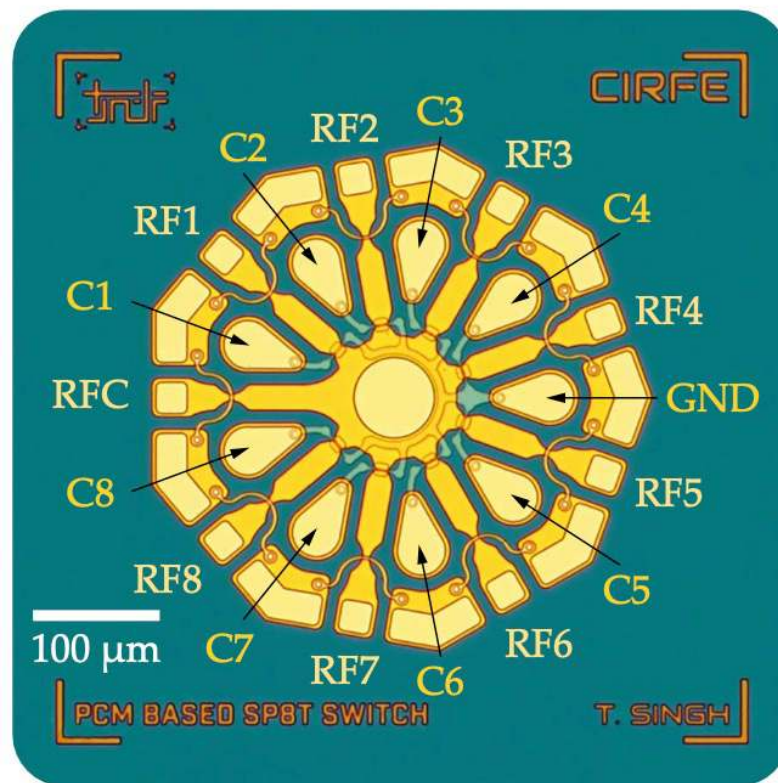
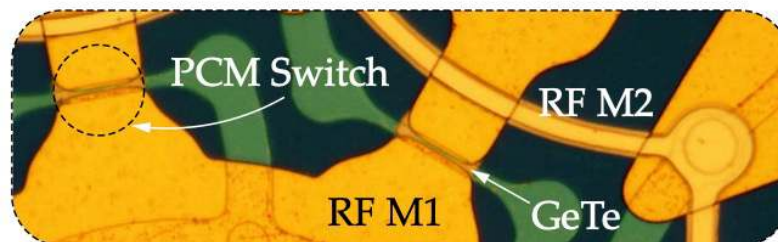
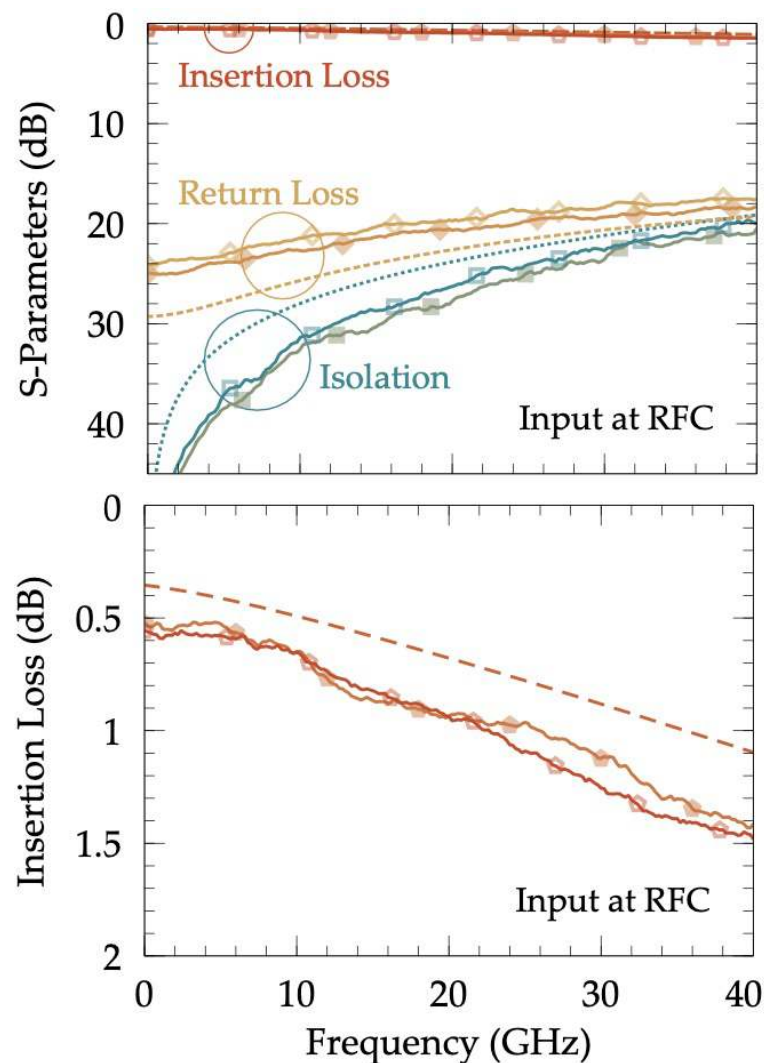




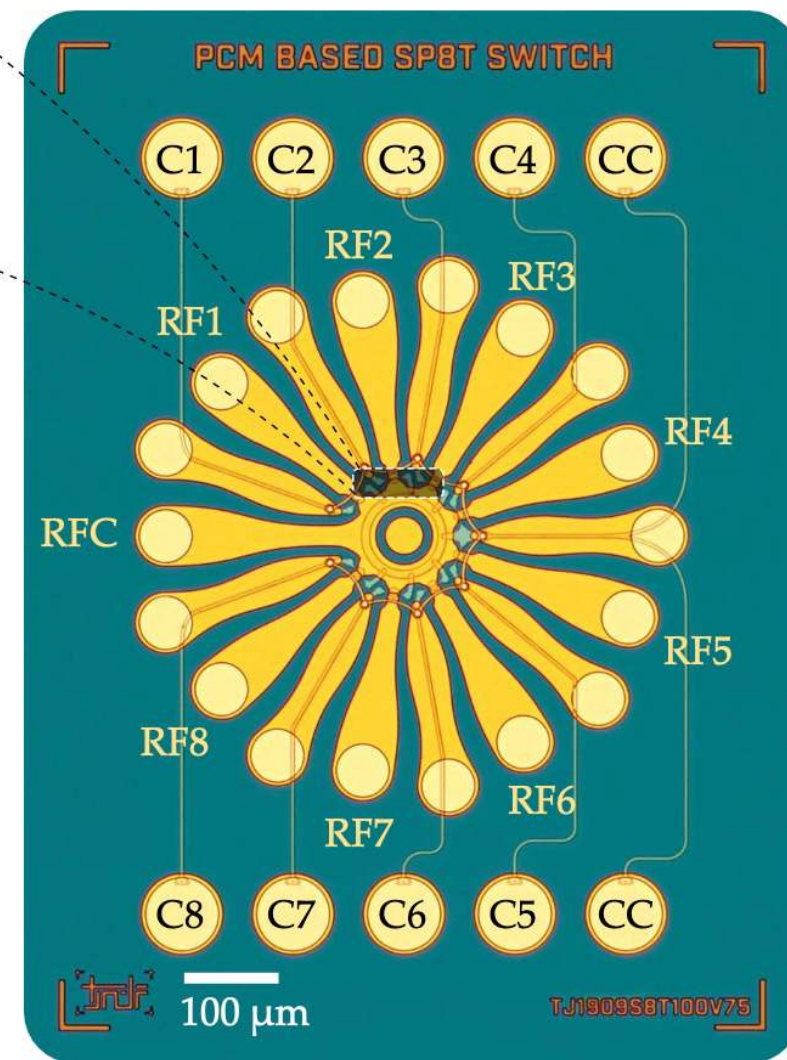
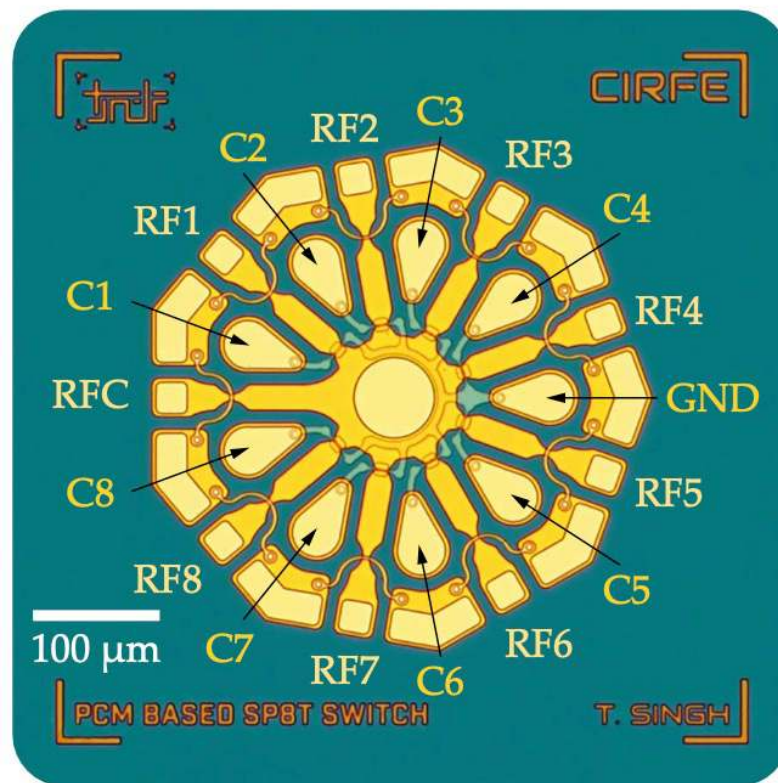
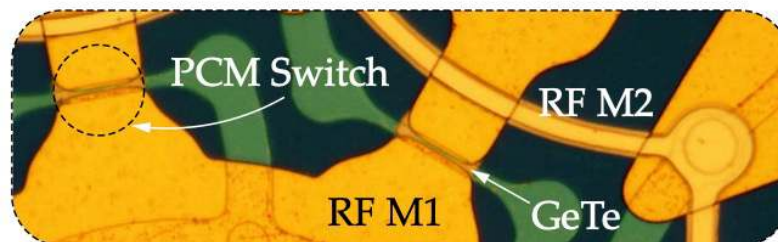
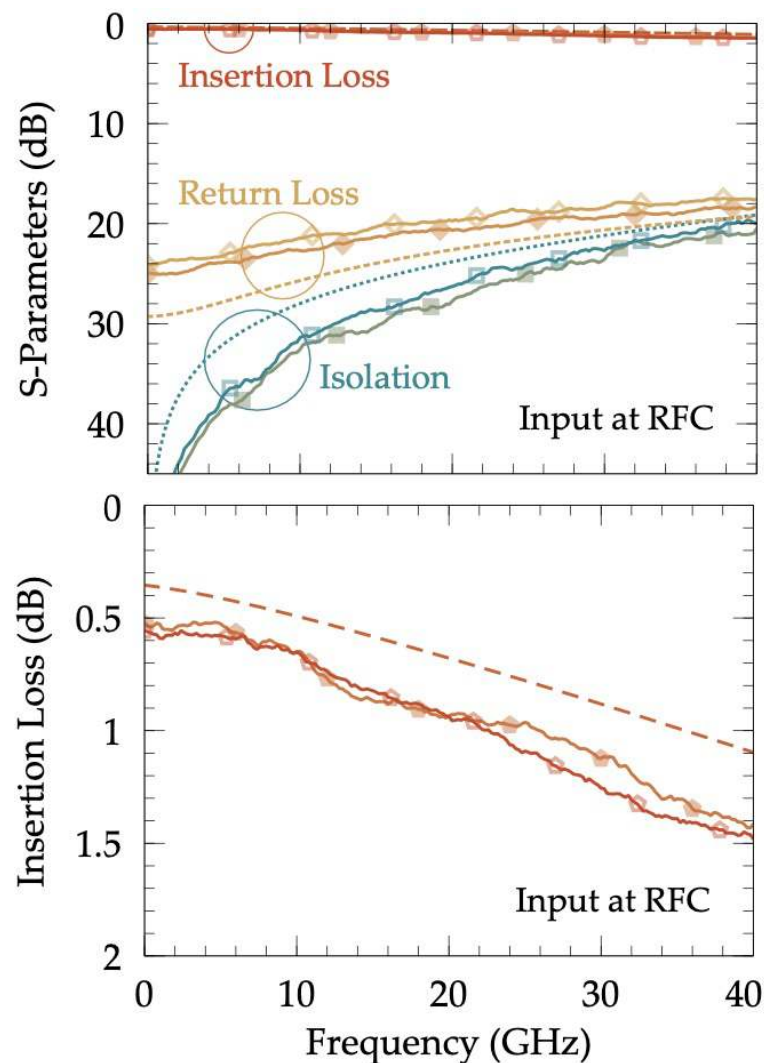
- Higher order multi-port switches are extremely challenging to design.
- Unique symmetrical design based on kaleidoscopic design approach.
- Ultra-compact design with eight output ports RF1-RF8 and one common port RFC.
- Chip area of  $0.0125 \text{ mm}^2$  with core radius,  $r = 70 \text{ }\mu\text{m}$ .





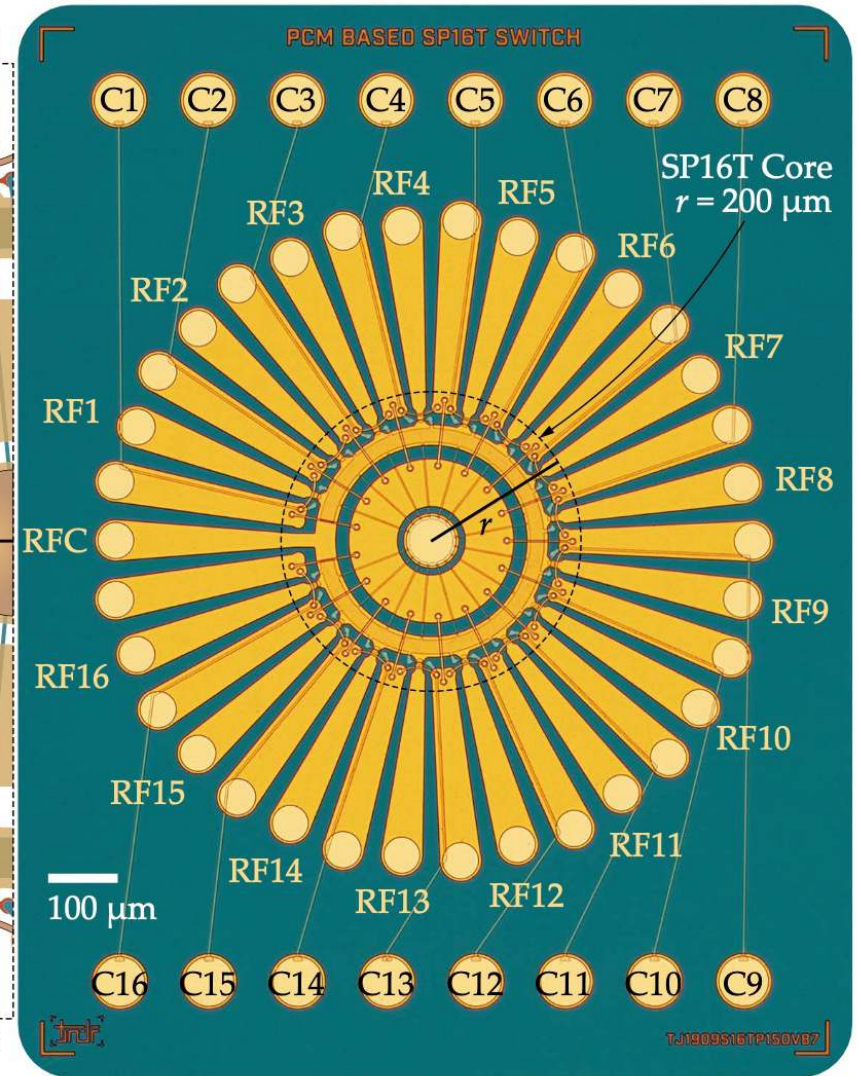
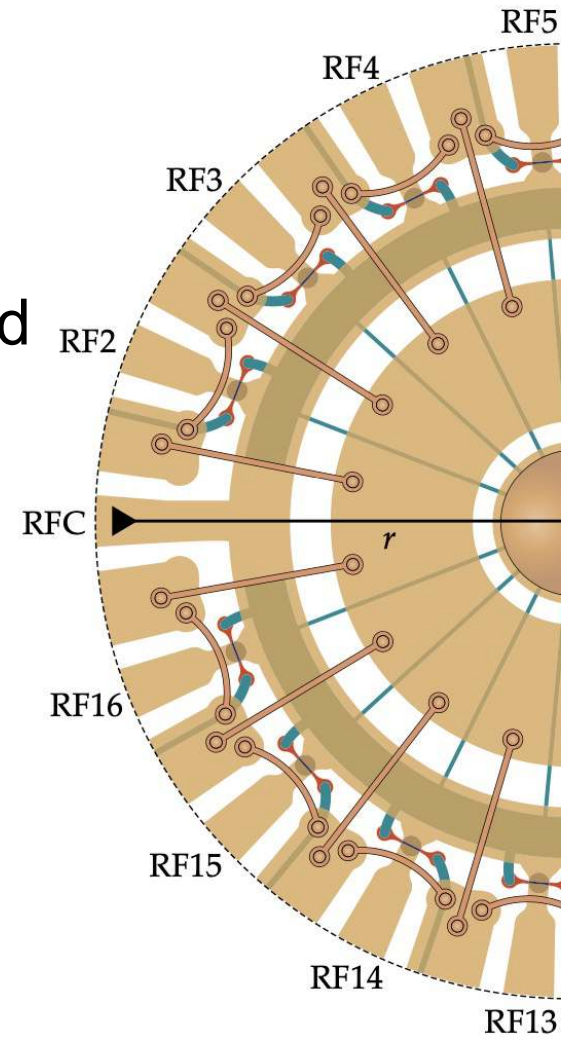




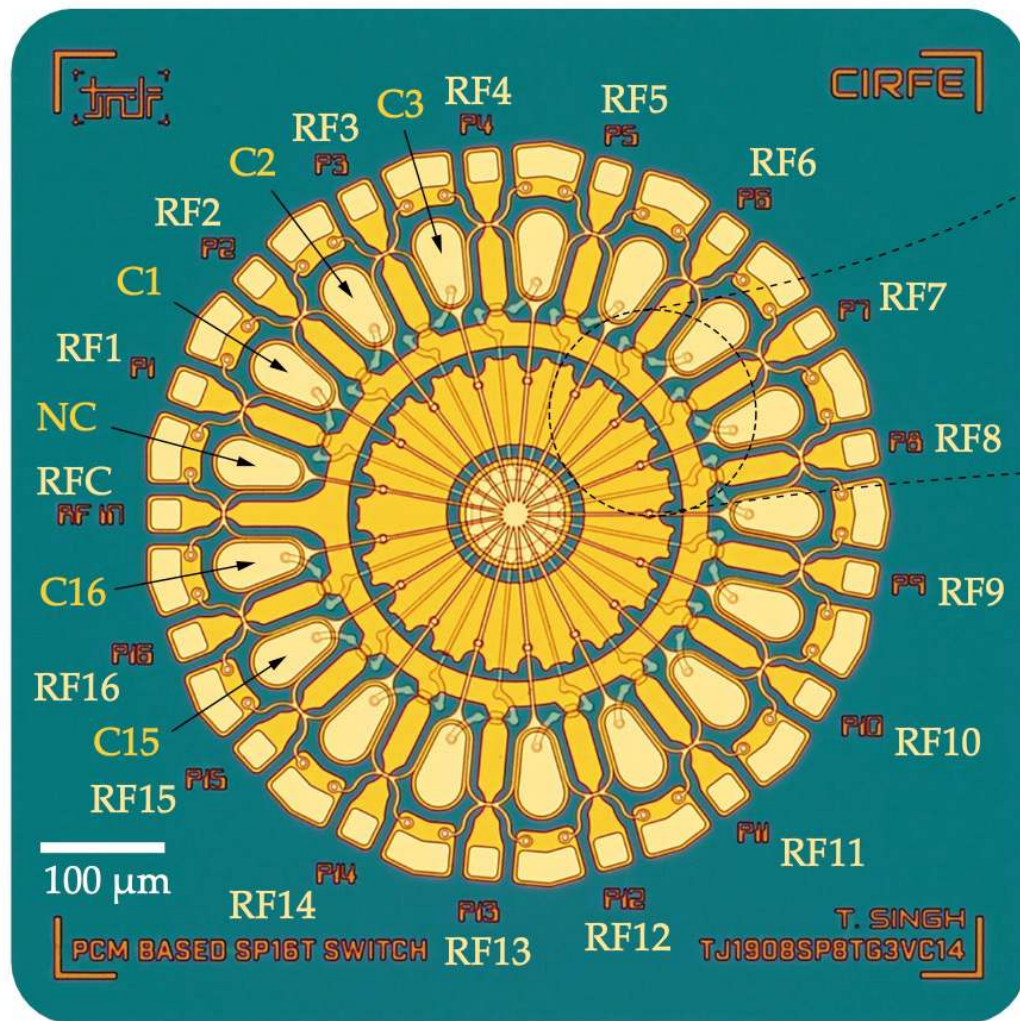




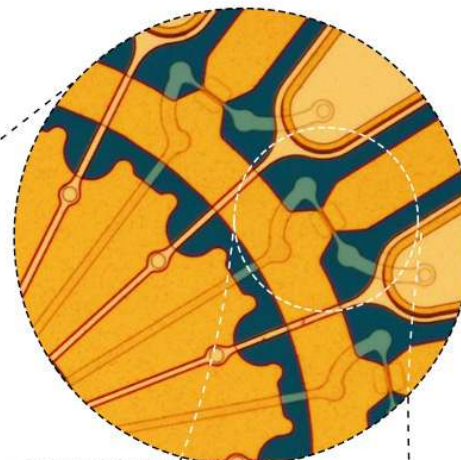
- Higher order multi-port switches are extremely challenging to design.
- Unique symmetrical design based on kaleidoscopic design approach.
- Ultra-compact design with eight output ports RF1-RF16 and one common port RFC.
- Chip area of  $0.3 \text{ mm}^2$  with core radius,  $r = 180 \text{ um}$ .



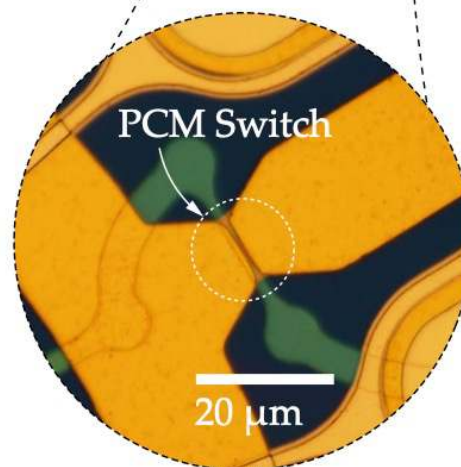




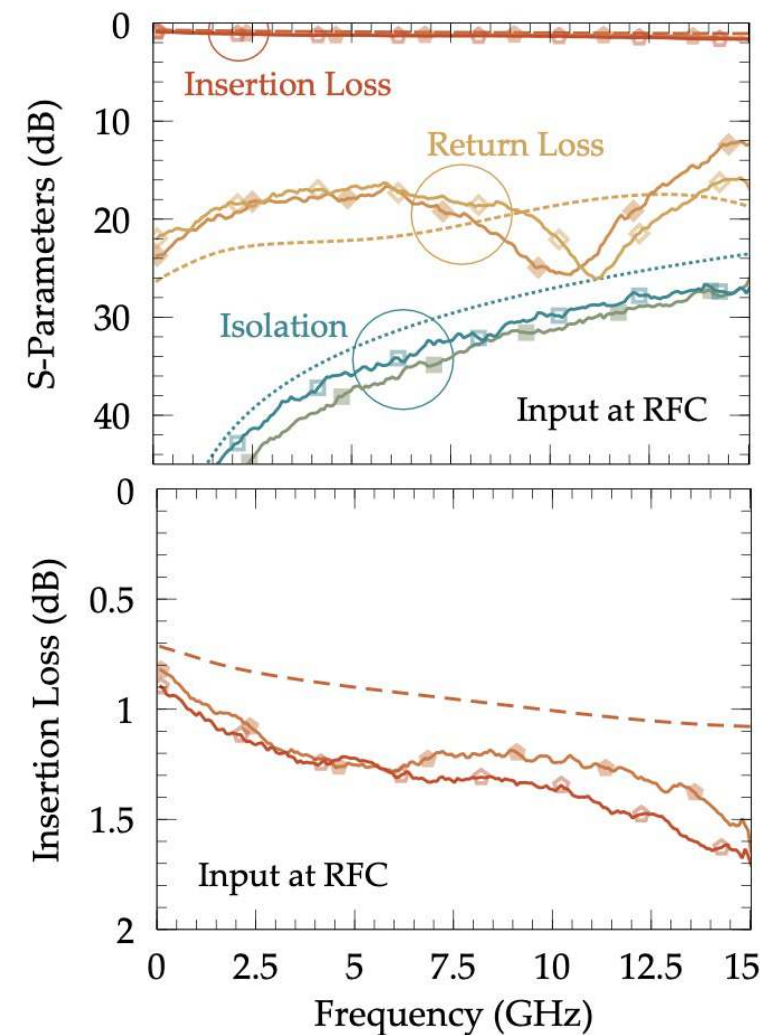
(a)



(b)



(c)

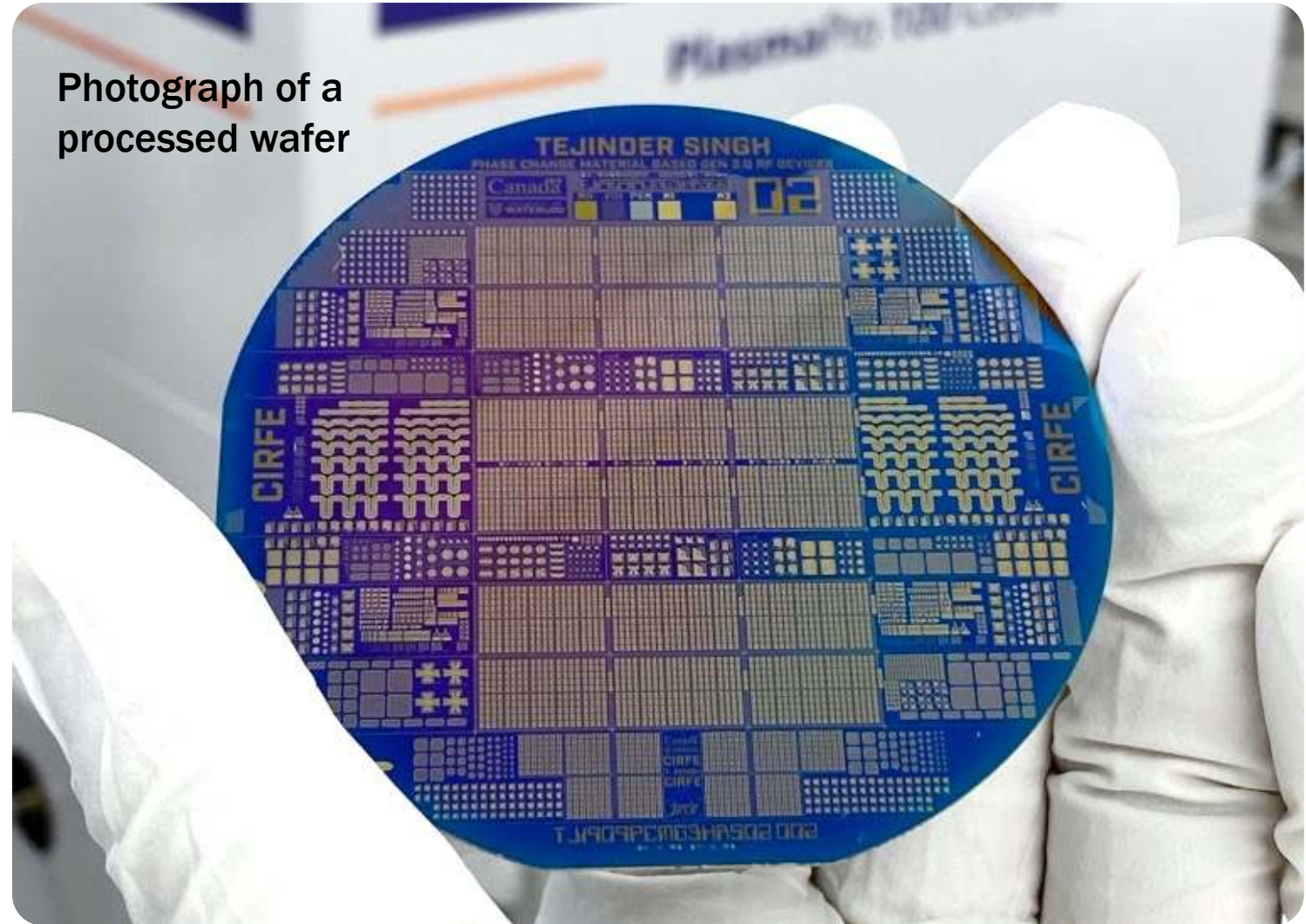


- **Ultra-compact DC-67 GHz** RF PCM GeTe-based switches are demonstrated with extensive performance analysis.
- Reliable RF PCM switches are tested for **> 1 million actuation cycles**.
- In-house developed **8-layer microfabrication process** is discussed
- Symmetrical multi-port switches are developed with equal performance at all the output ports
- SP2T, SP3T switches are developed for DC-67 GHz, SP8T switches for DC-40 GHz, and SP16T are designed and measured for DC-15 GHz with excellent RF performance.



# THANK YOU!

Photograph of a  
processed wafer



Forward your questions to

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