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Resistance Ratio Enhancement in Chalcogenide Phase-Change RF Switches at Cryogenic Temperatures

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Outline

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

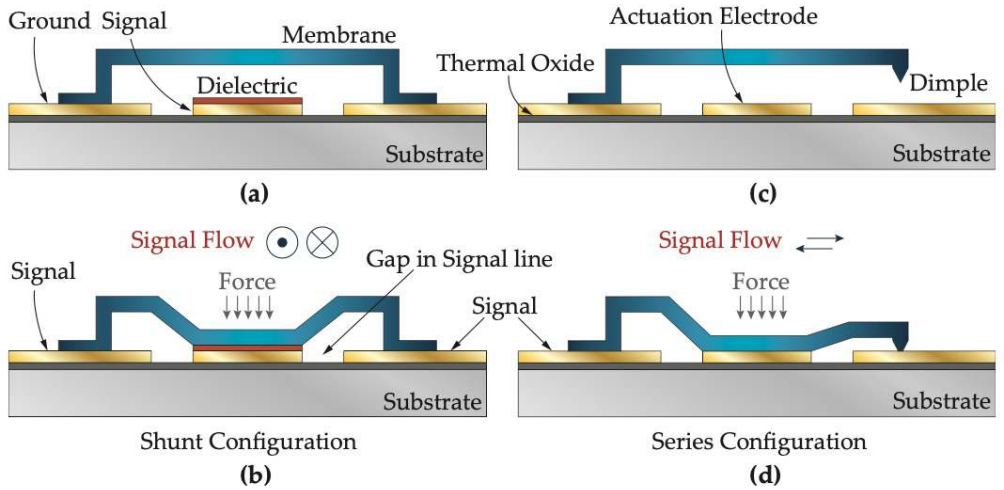
Introduction

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

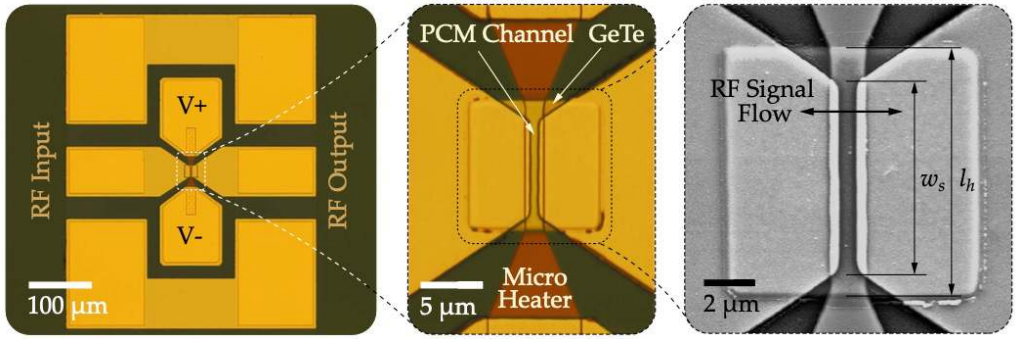
Waveguide

Coaxial

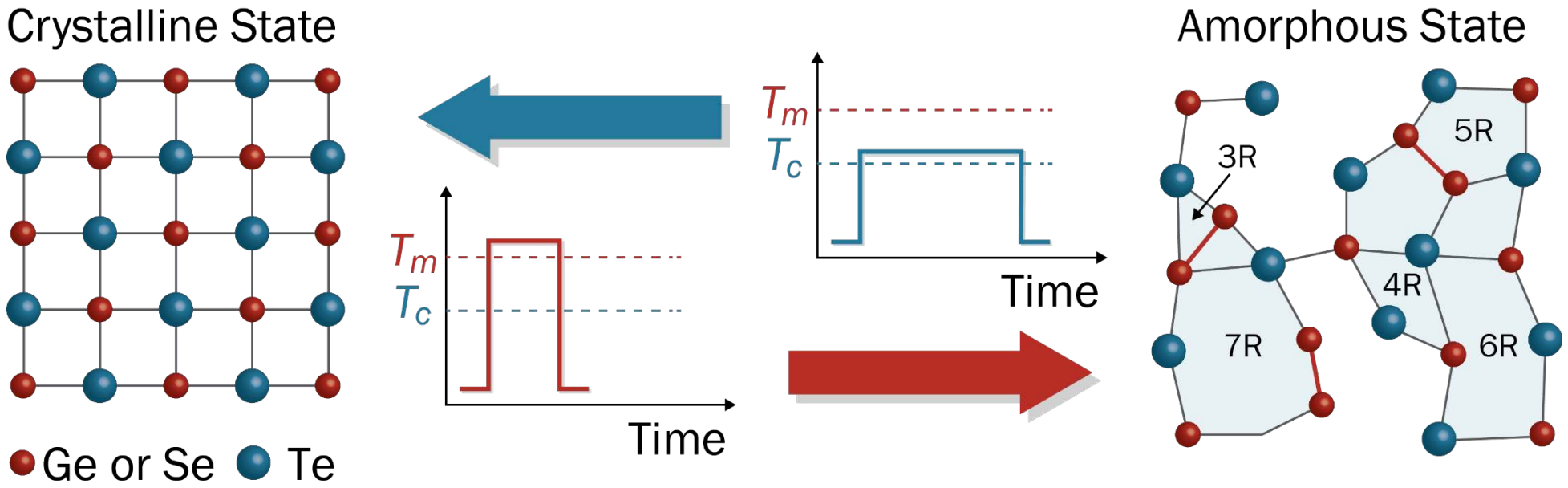
MEMS



Phase-Change



Phase Change Materials

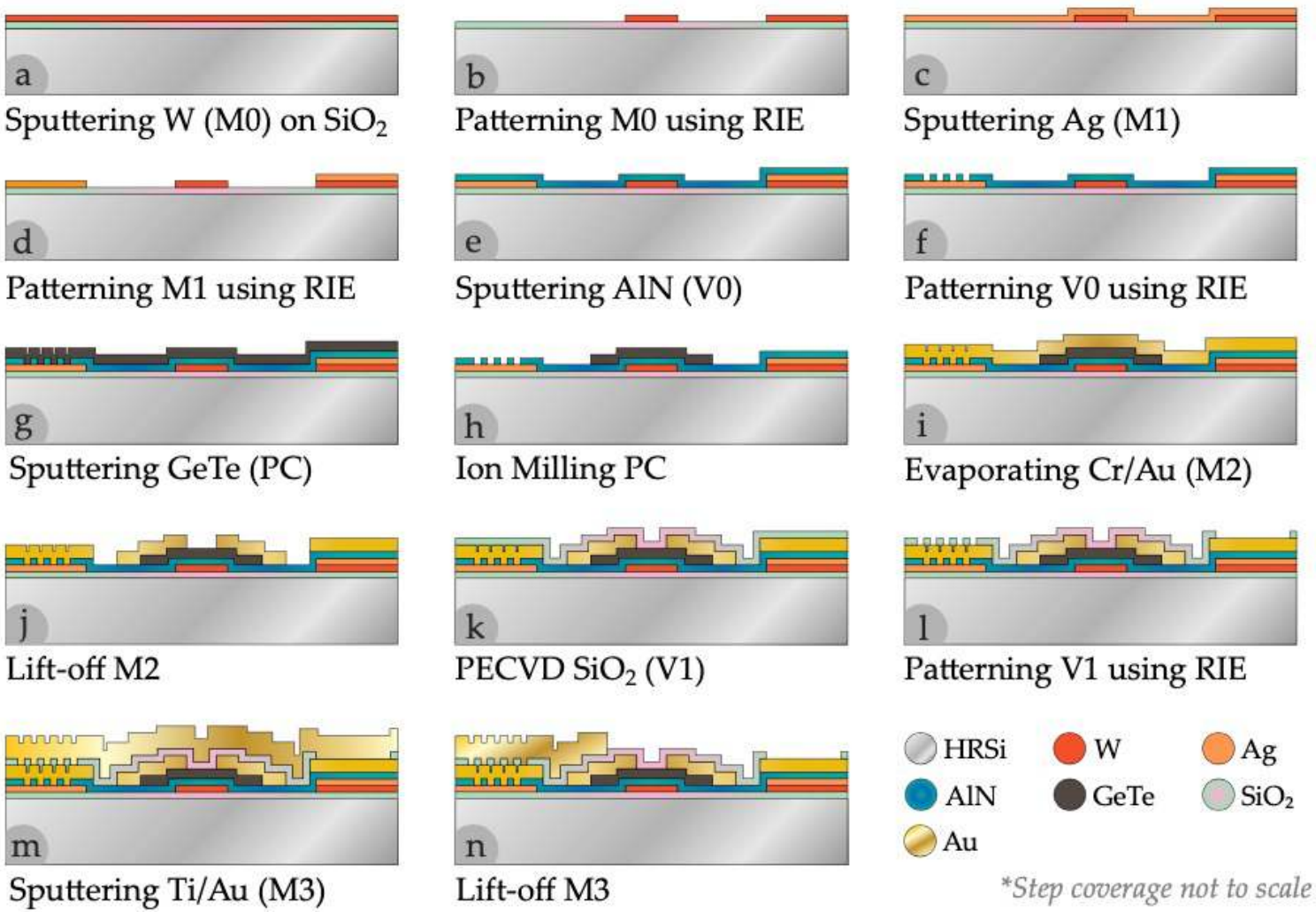


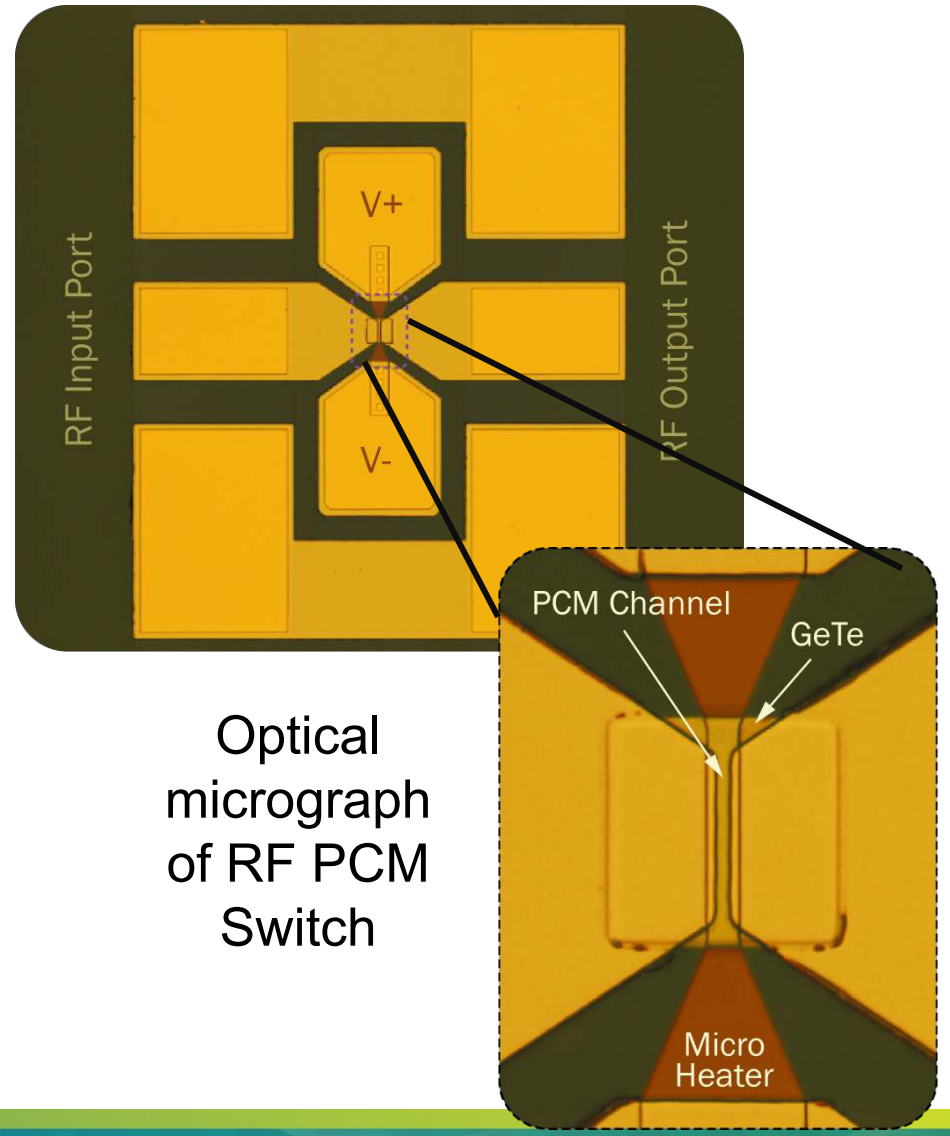
Transition between the amorphous (insulating) and the crystalline (conductive) states is accomplished by heating and cooling the PCM

Various RF Switch Technologies

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

Fabrication Process Flow

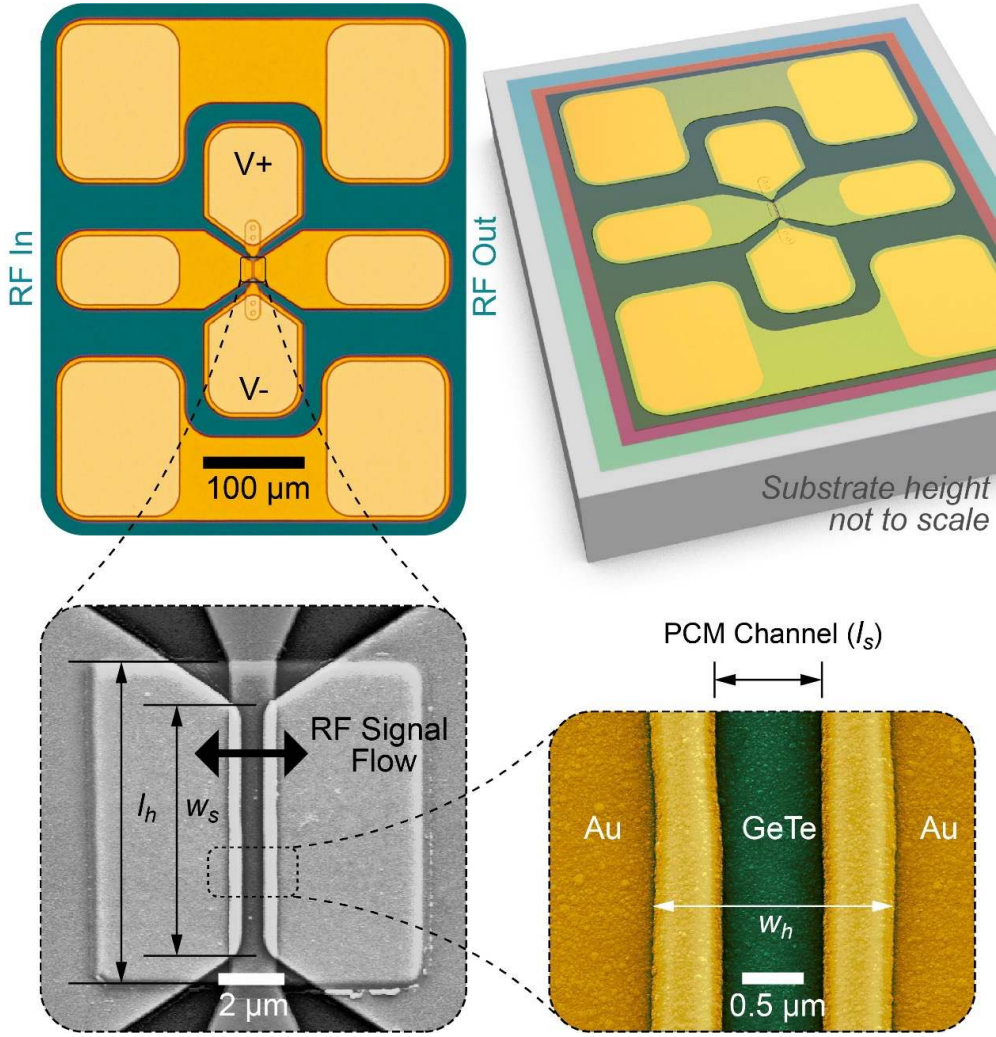




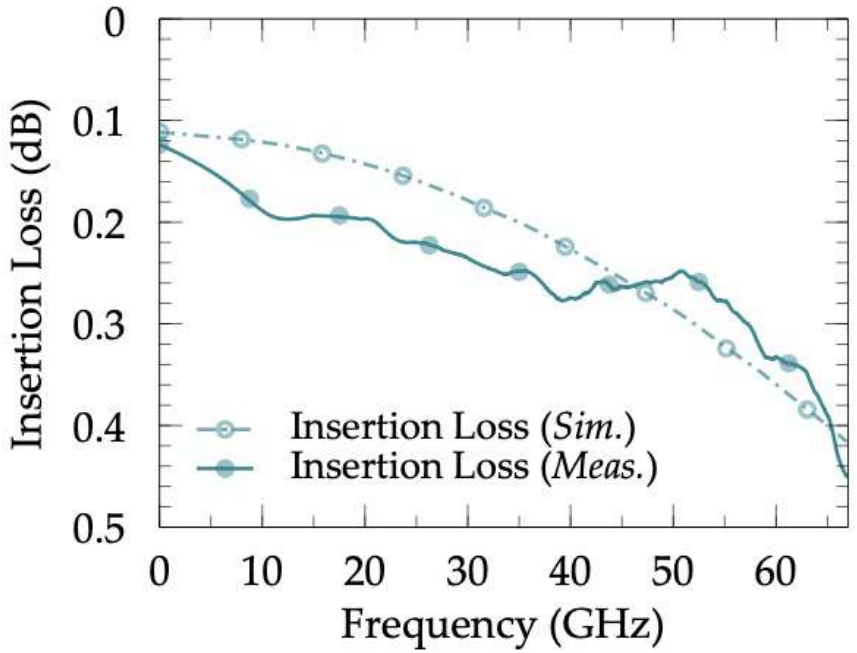
Optical micrograph of RF PCM Switch

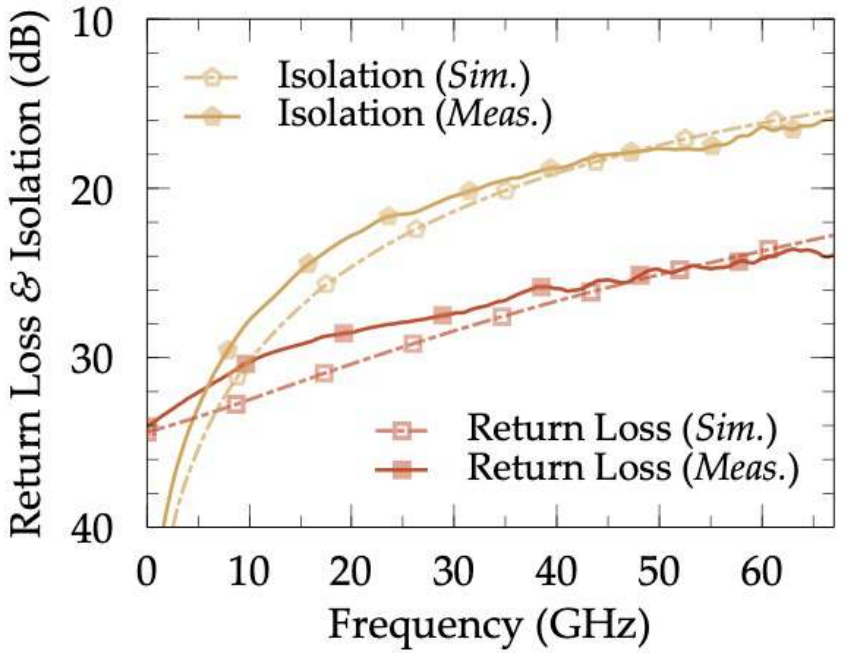
RF PCM SPST Switch Unit Cells

- 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 µm x 30 µm**
- 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 µs**
- Tested for **> 1 million** reliable switch cycles

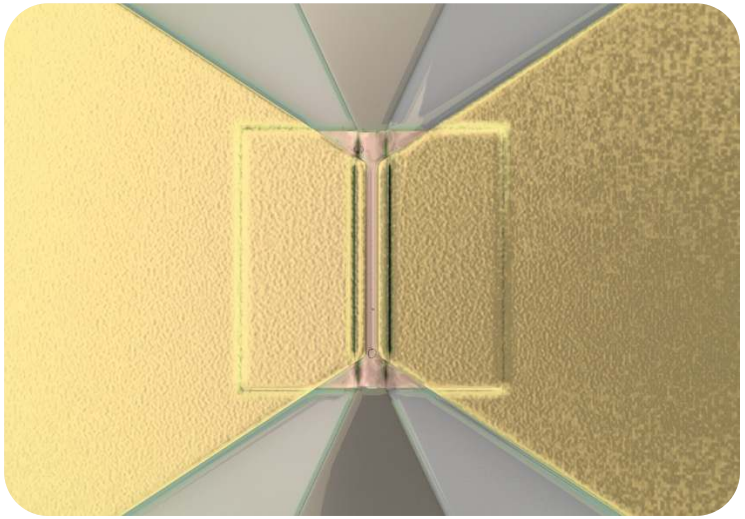


RF Performance of SPST Switch





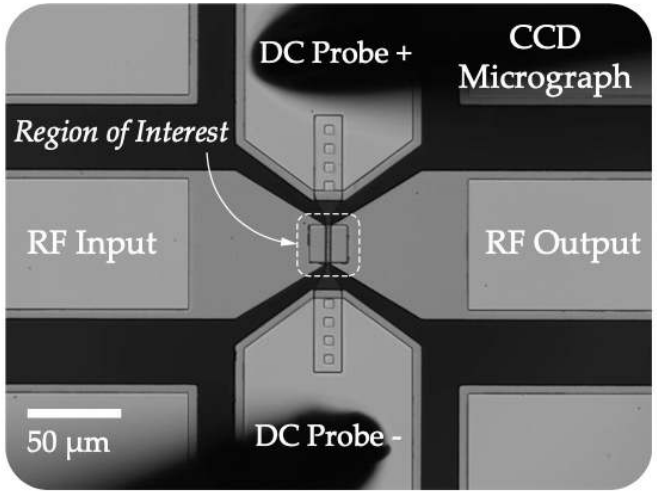
w_s	l_s	w_h	l_h	R_{on}	R_{off}/R_{on} Ratio
10 µm	3 µm	2 µm	20 µm	4.9 Ω	1.2×10^4
15 µm	3 µm	3 µm	25 µm	3.7 Ω	1.6×10^4
15 µm	2 µm	3 µm	30 µm	2.4 Ω	2.9×10^4
20 µm	2 µm	2 µm	35 µm	1.8 Ω	3.9×10^4
20 µm	3 µm	3 µm	35 µm	2.3 Ω	2.6×10^4
10 µm	1.2 µm	0.8 µm	20 µm	1.61 Ω	4.35×10^4



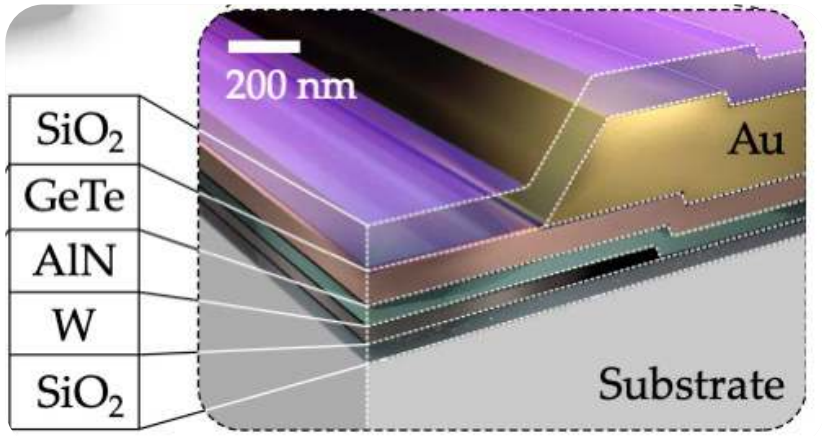
3D rendered view of RF PCM GeTe-Based SPST Switch

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.

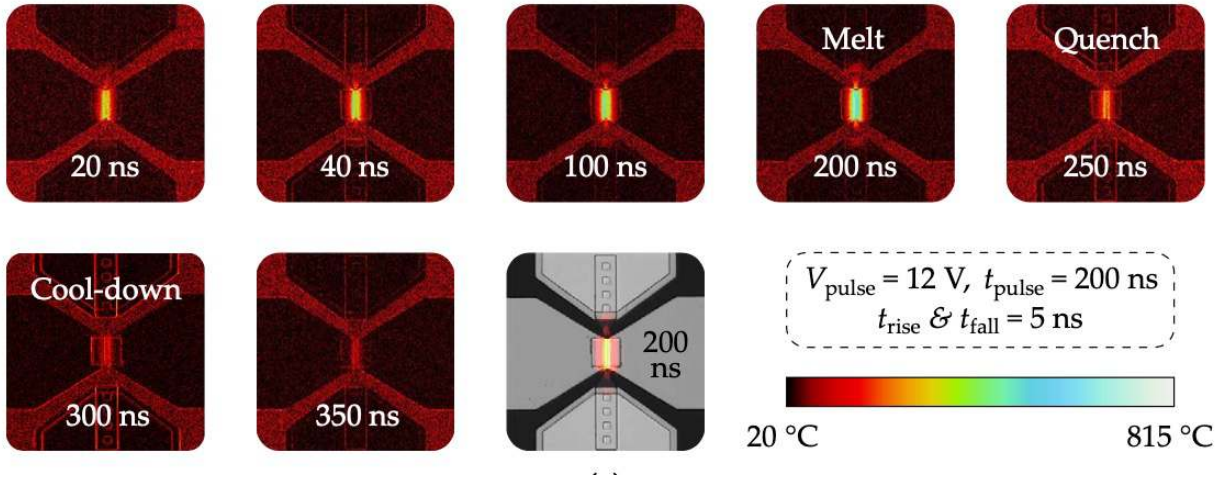
Thermal Crosstalk Investigation



(a)

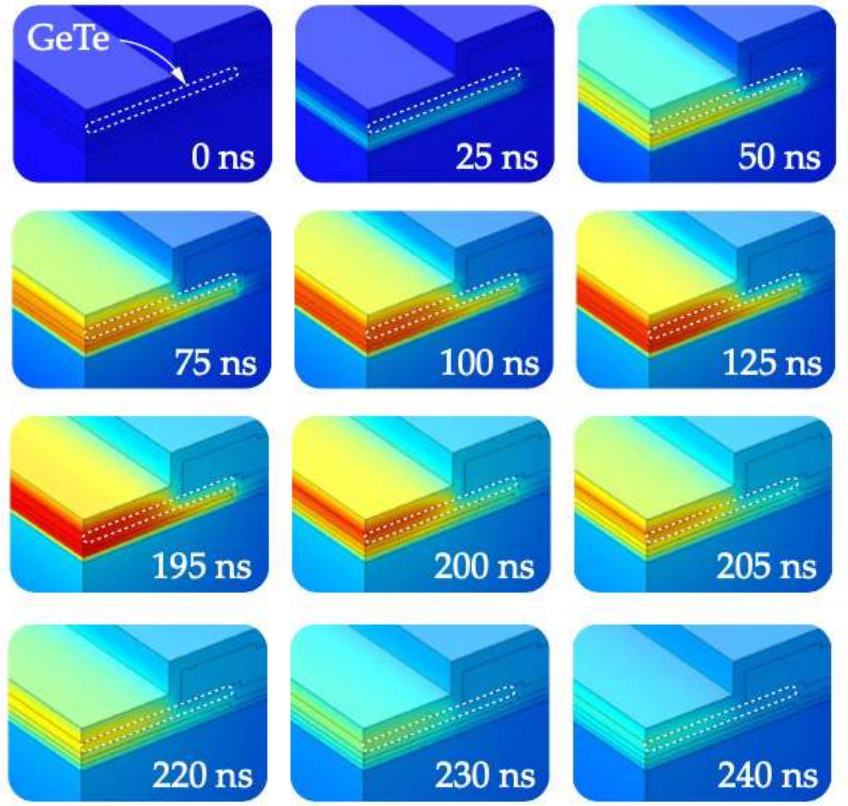


(b)



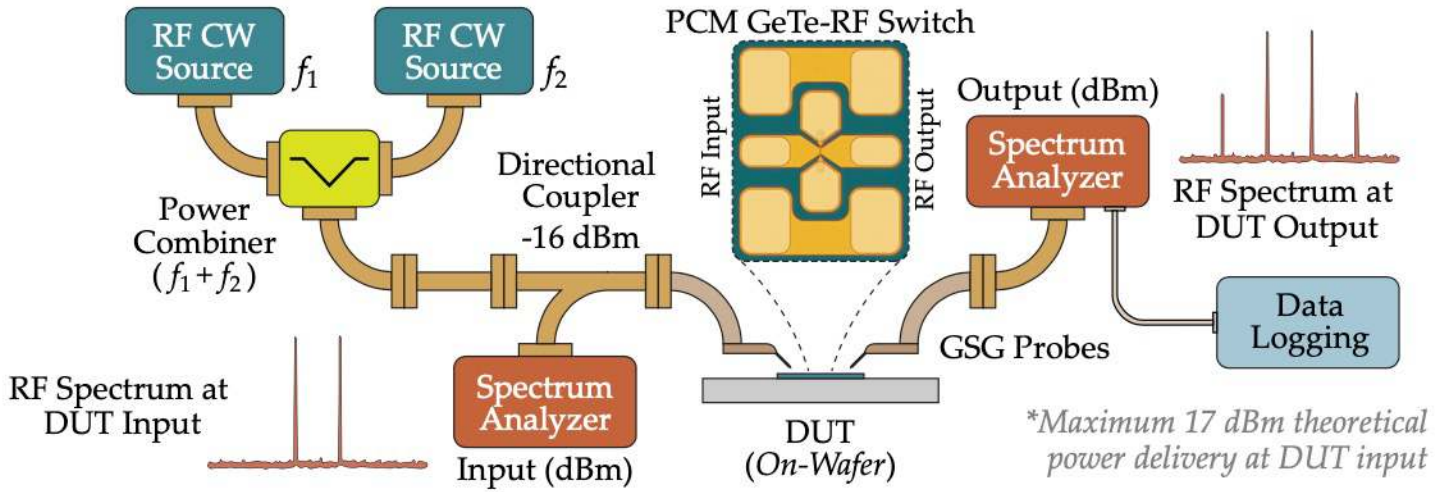
(c)

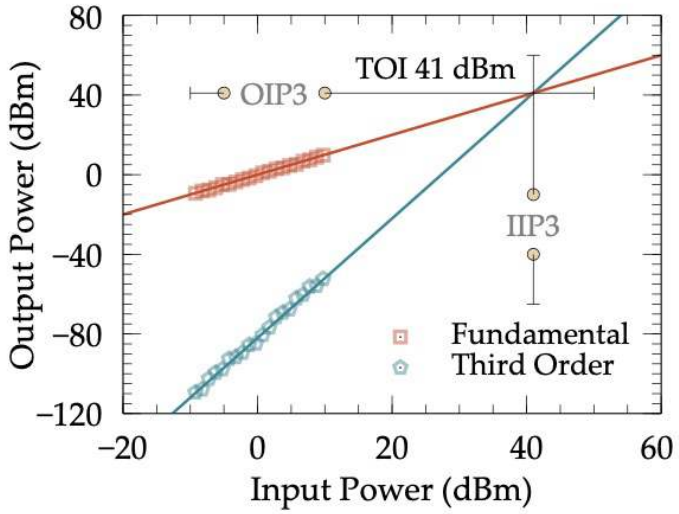
FEM Transient Simulations

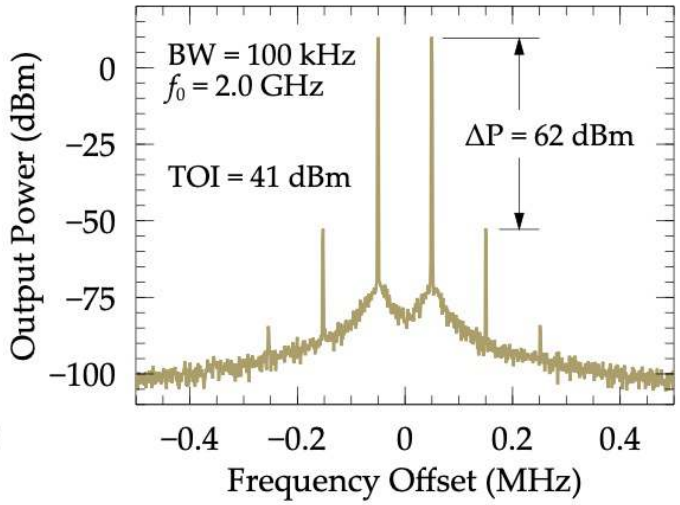


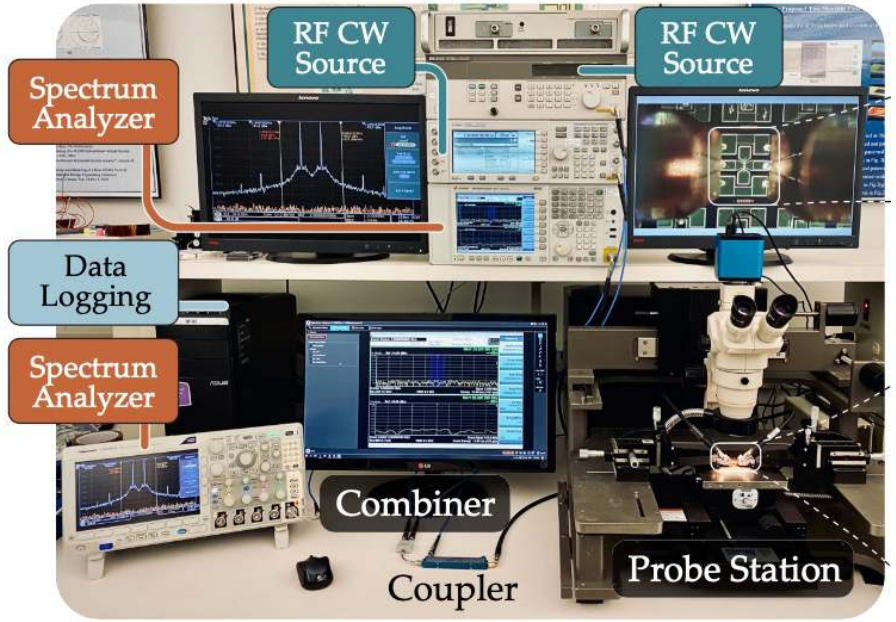
Transient thermal imaging of RF PCM SPST switch for investigating thermal crosstalk

TOI Measurement



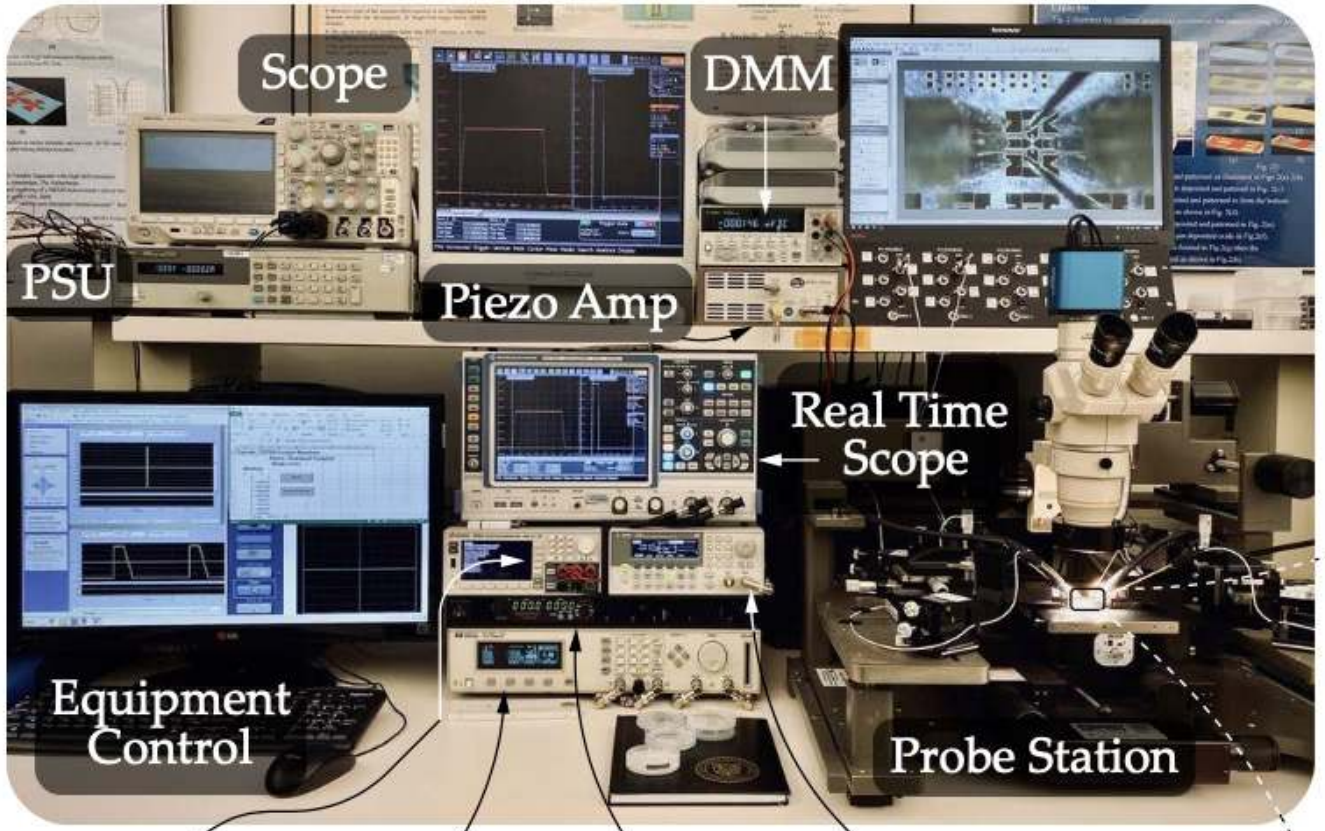


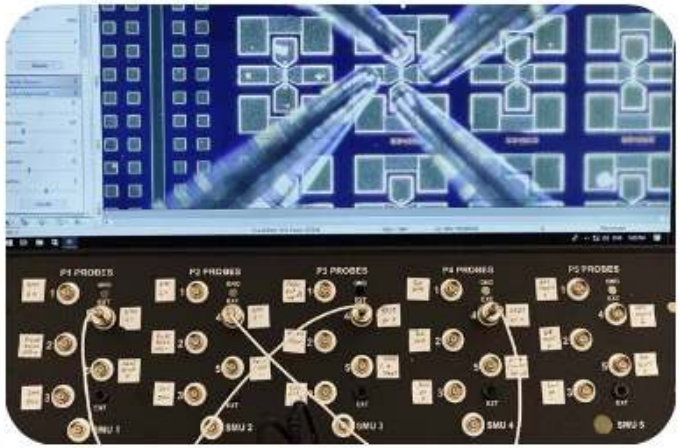




Centre Frequency (f_0)	Tone Separation (BW = f_2 - f_1)	Measured IP3 / TOI
2 GHz	100 kHz	41 dBm
2 GHz	500 kHz	42 dBm
2 GHz	1 MHz	45 dBm
3 GHz	100 kHz	42 dBm
3 GHz	500 kHz	42 dBm
3 GHz	1 MHz	44 dBm

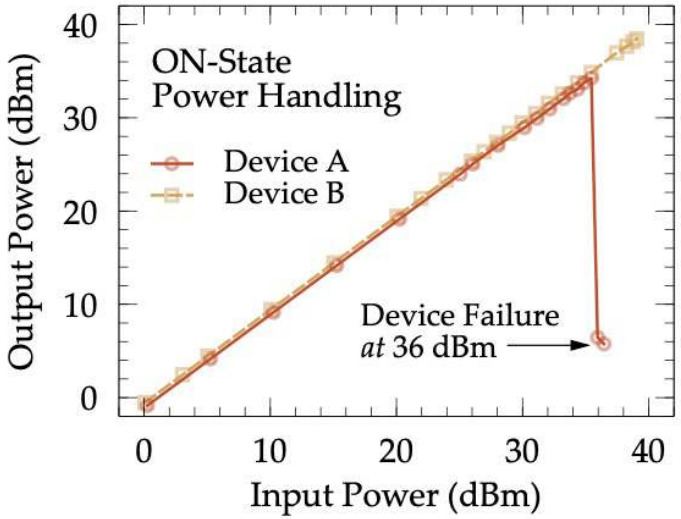
RF / DC Test Setup Photograph





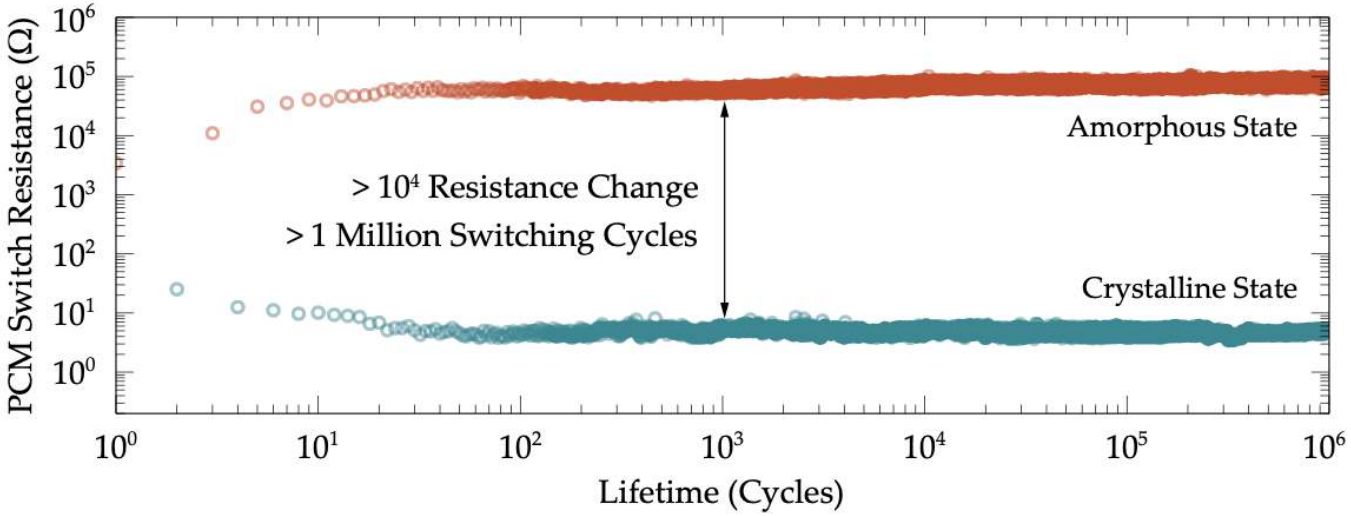
Modular Connection Matrix

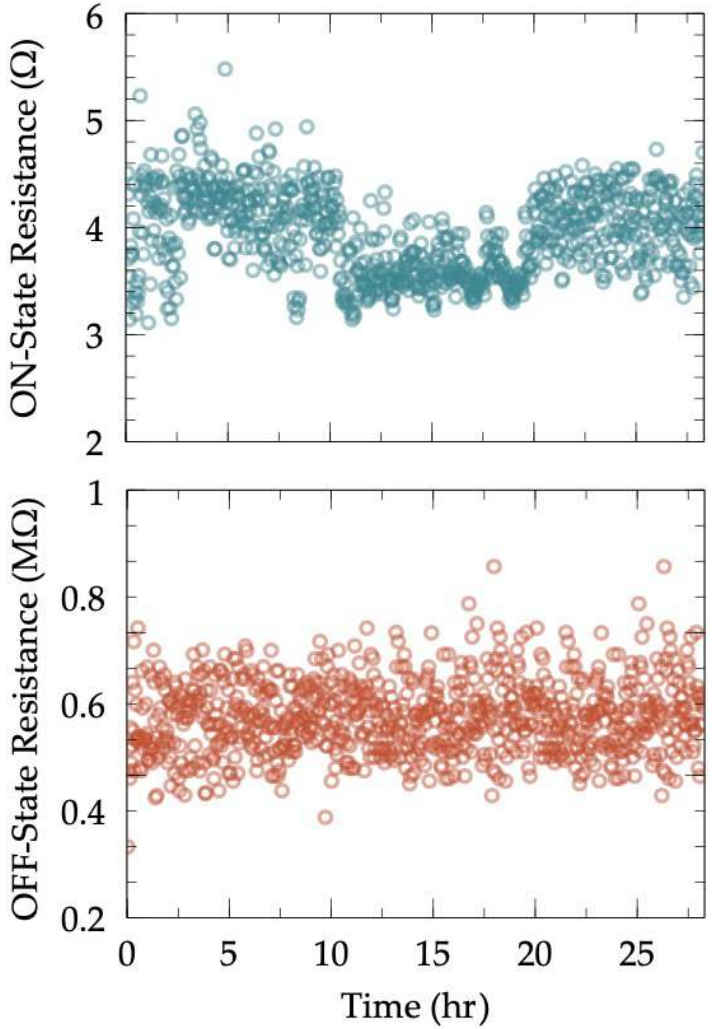
Power Handling and Reliability



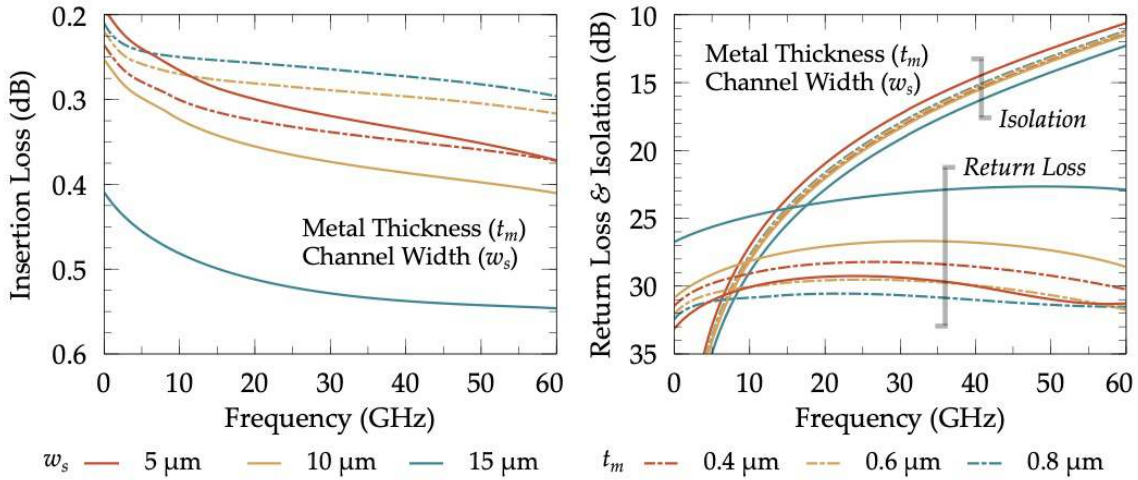
Device A: **35.5 dBm**
(narrow PCM channel)

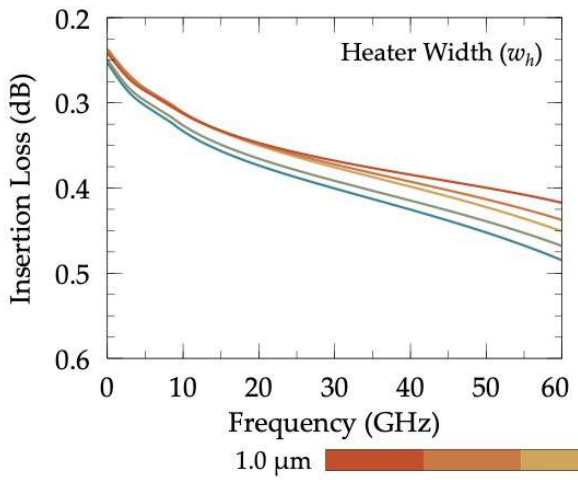
Device B: **> 40 dBm**
(wide PCM channel)

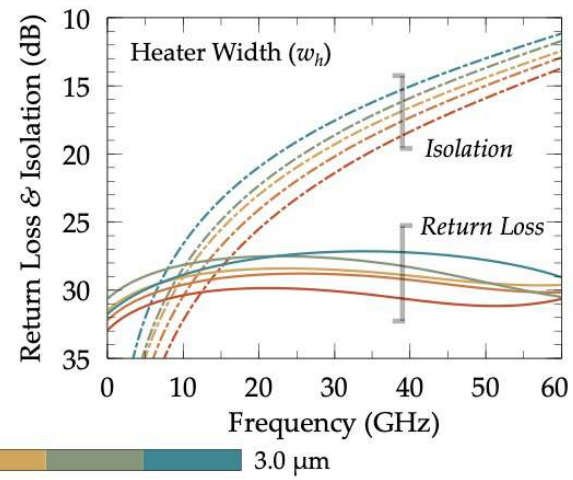


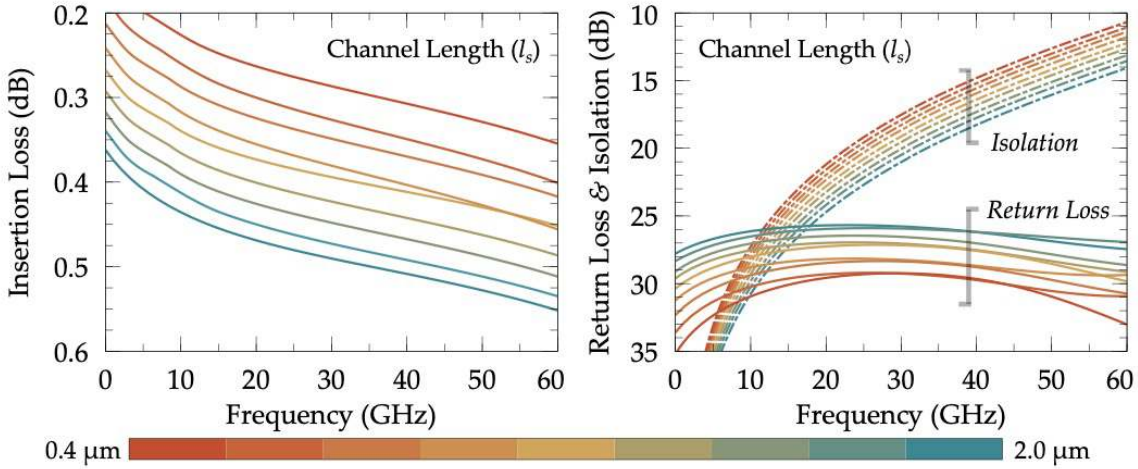


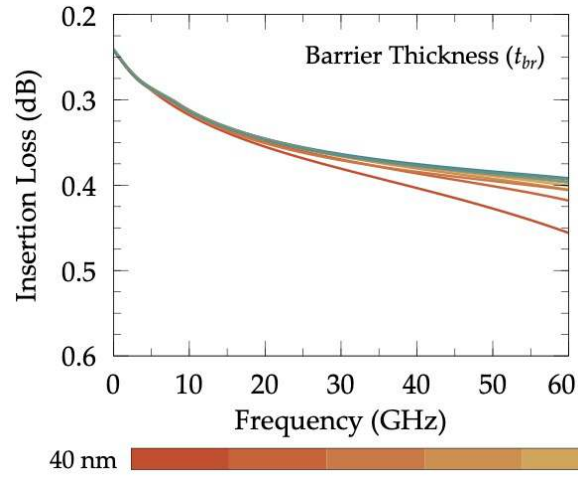
Parametric Design Parameters

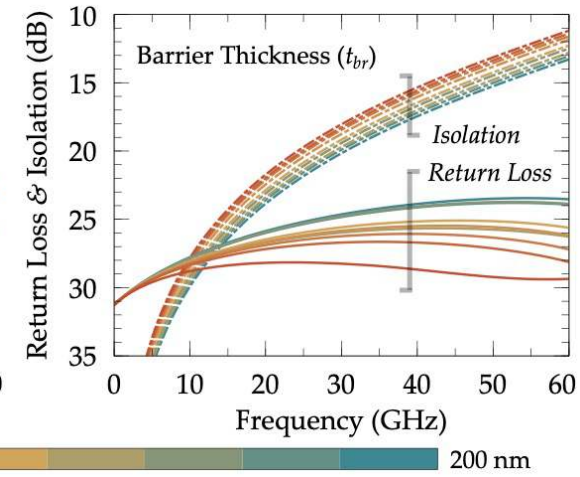




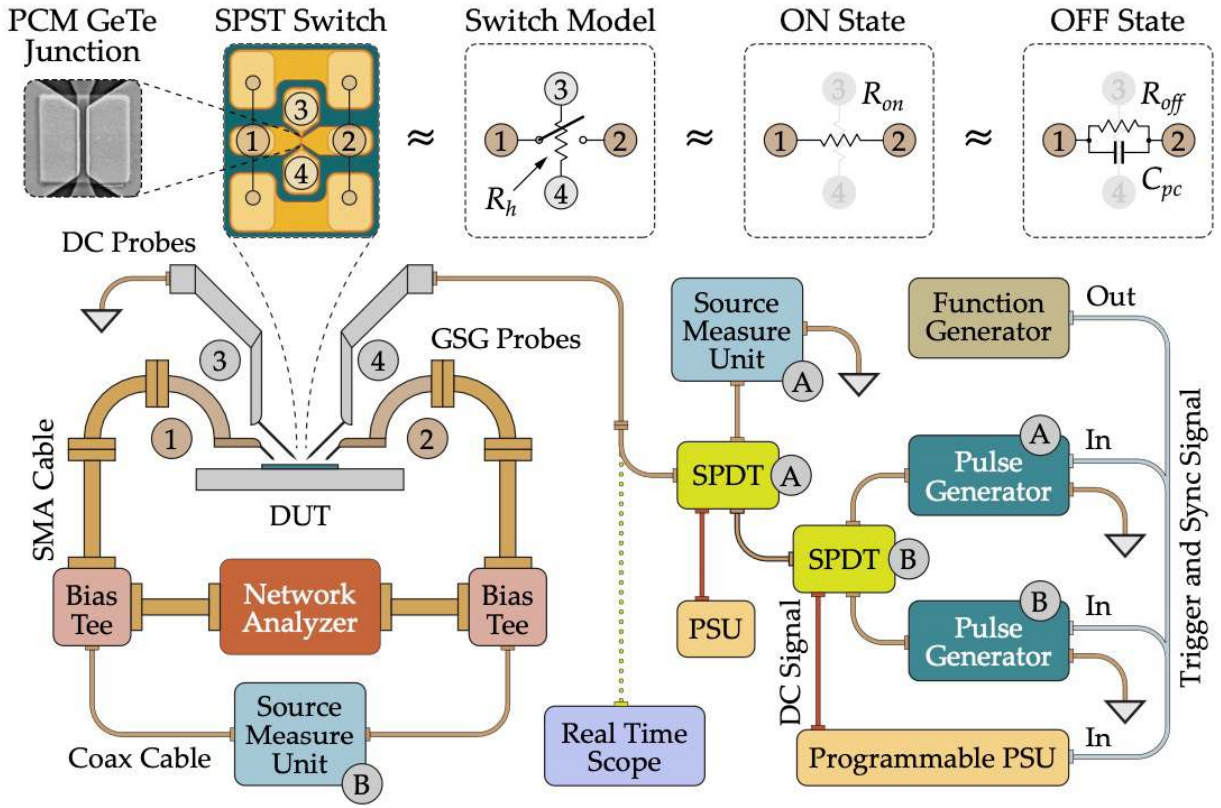


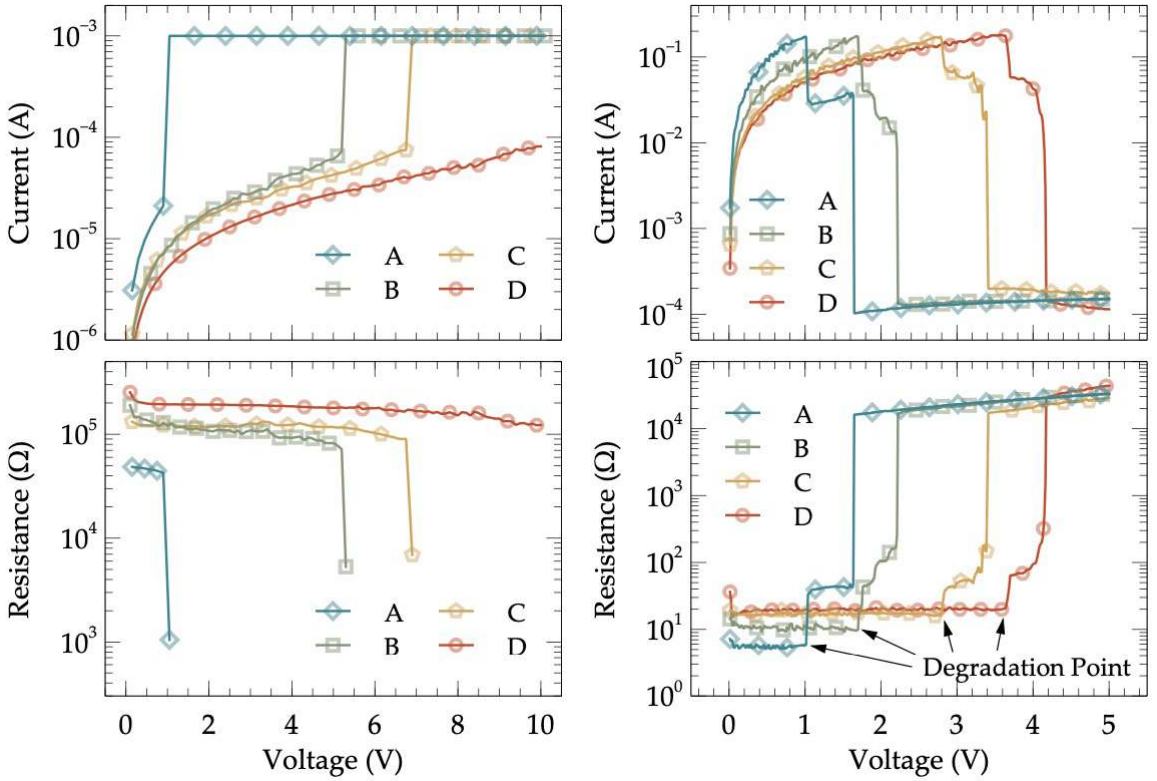






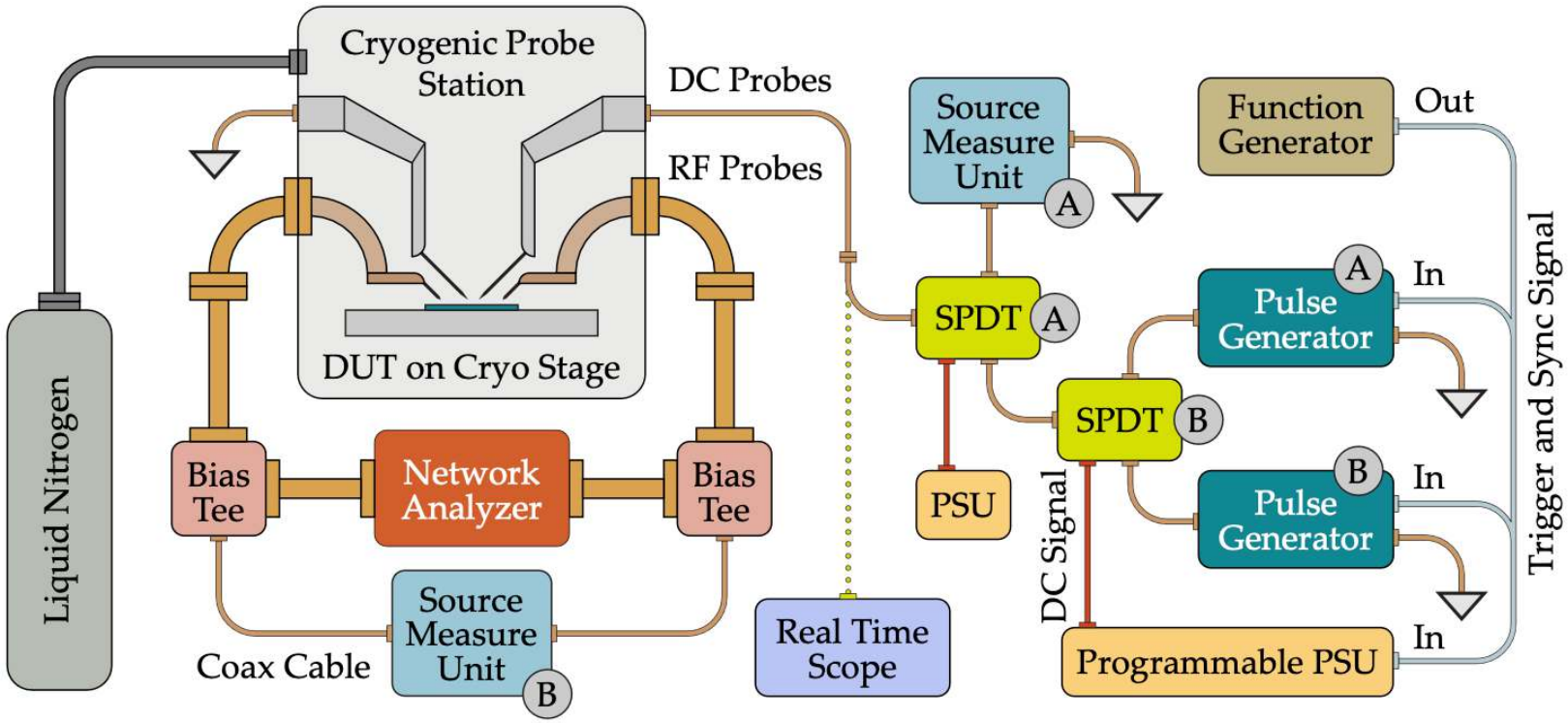
Current Carrying Capability





Cryogenic Measurements

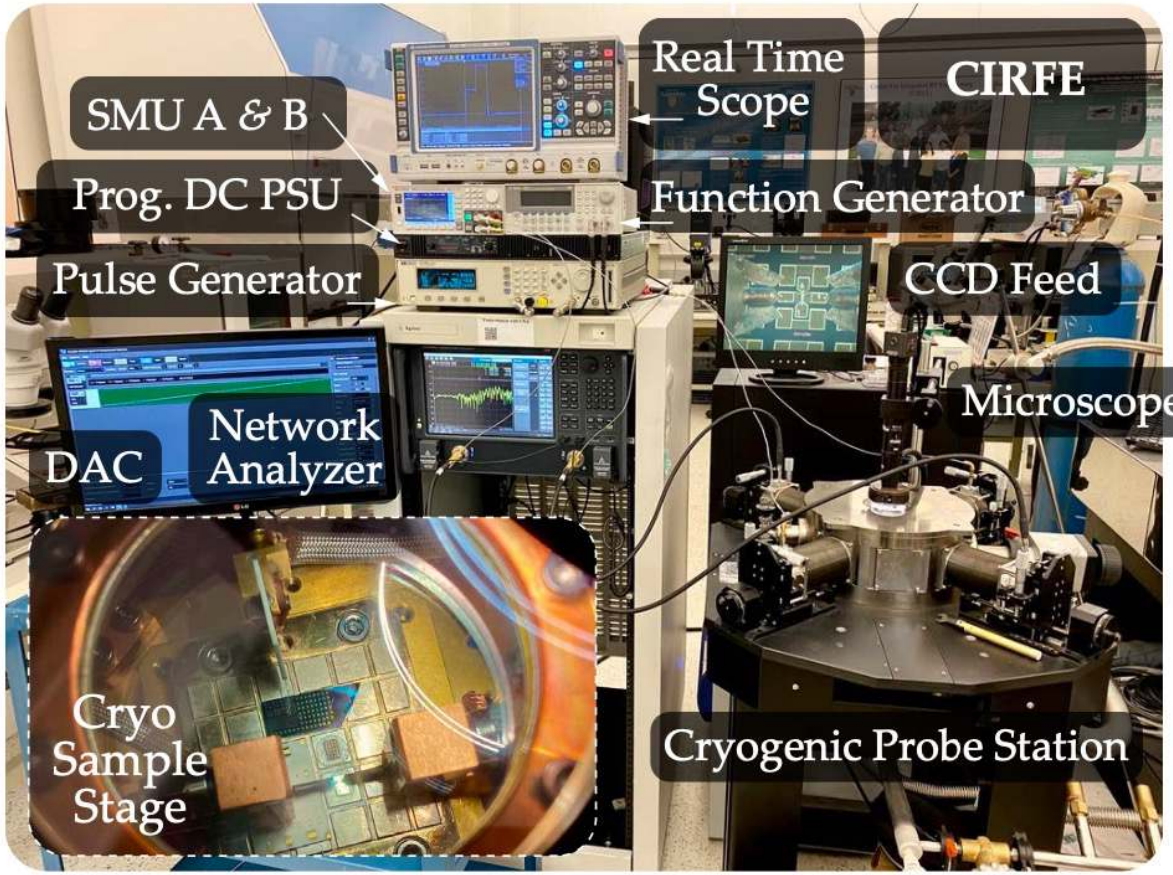
Test setup to simultaneously measure RF and DC performance of the devices.

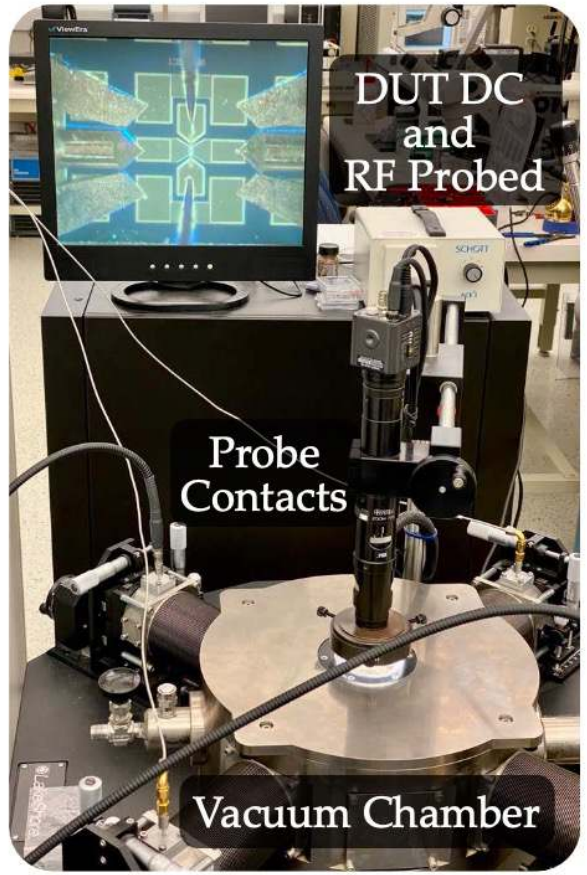


Measurement are performed at 77 K using liquid nitrogen (LN).

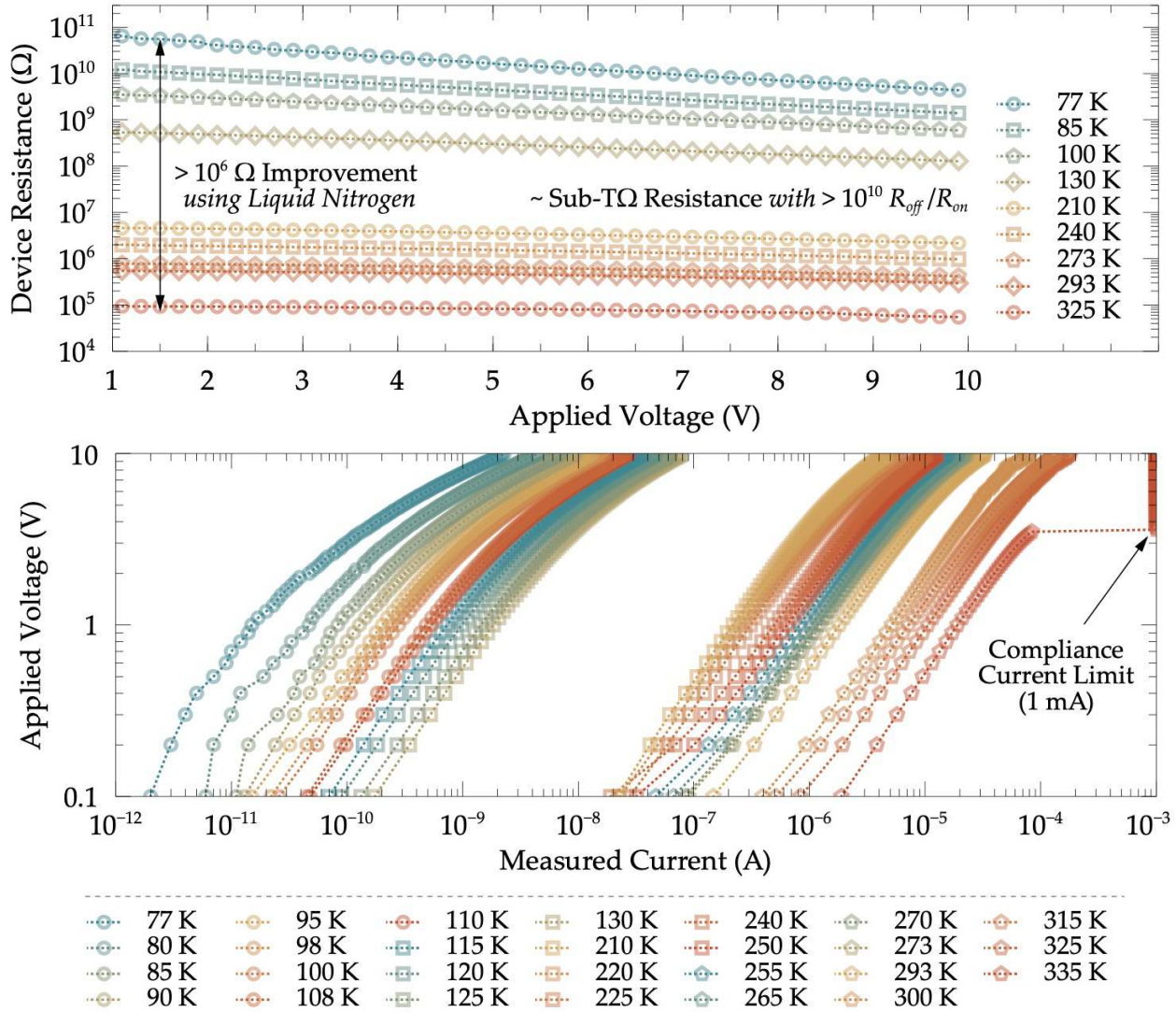
Liquid helium (LH) can further enhance the performance but the delta gains from using LH is minimal compared to LN only.

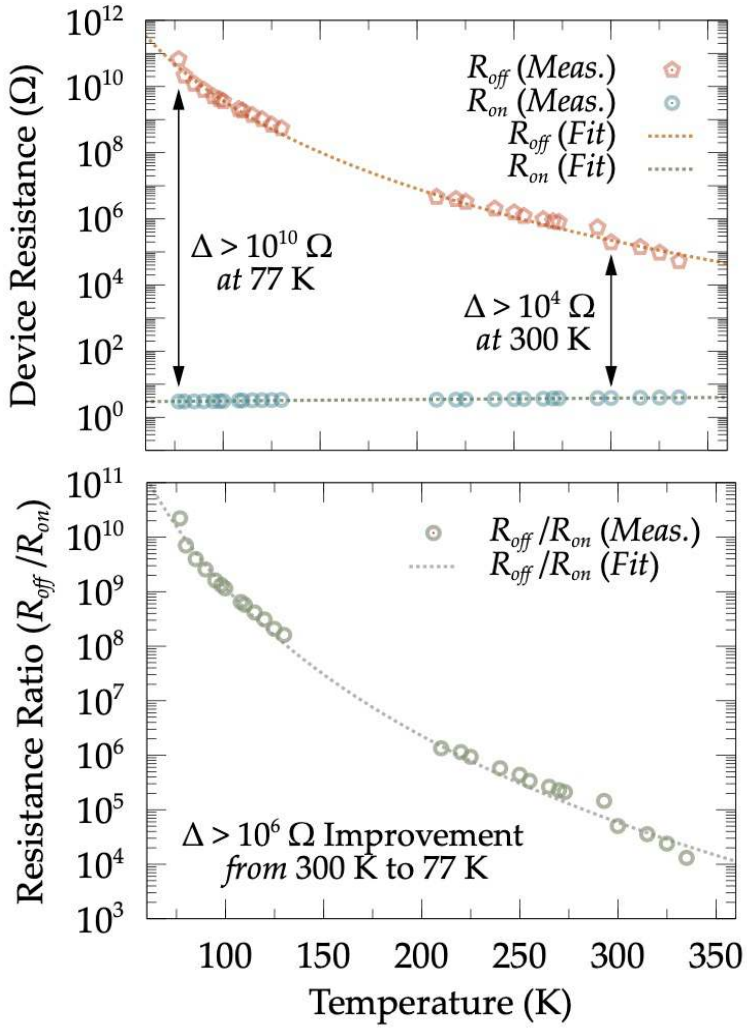
Cryogenic Testbed





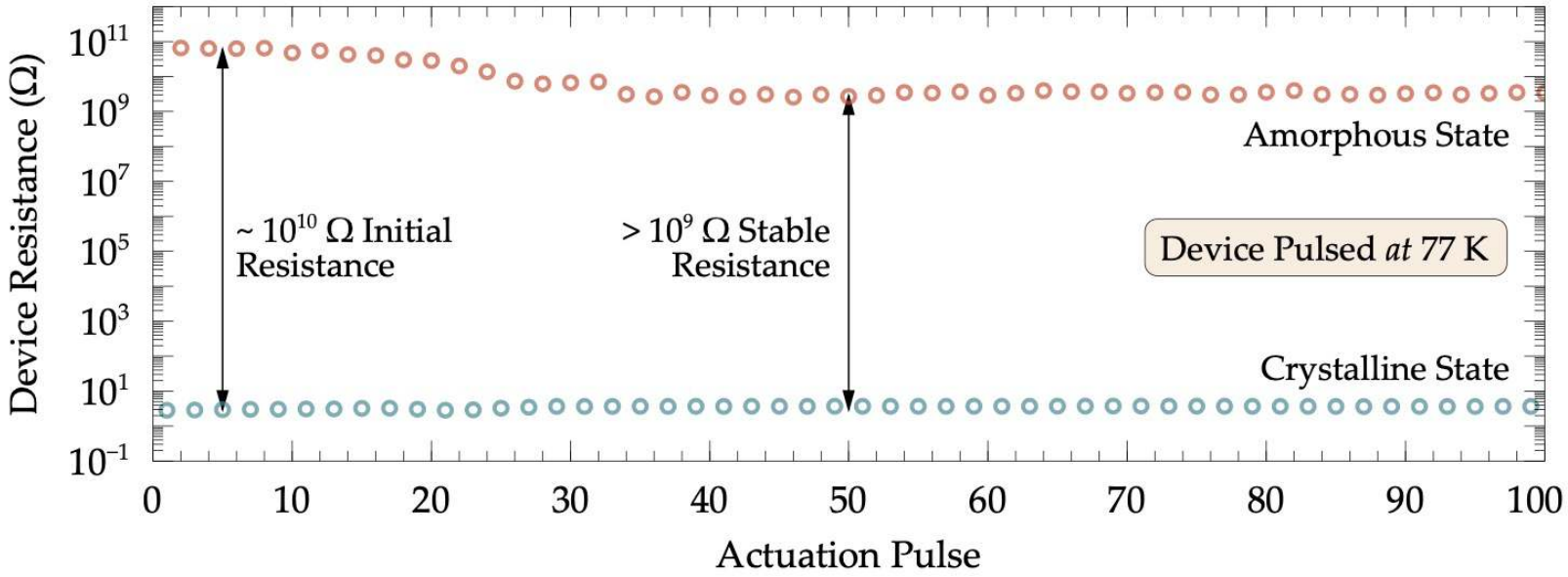
IV Measurements





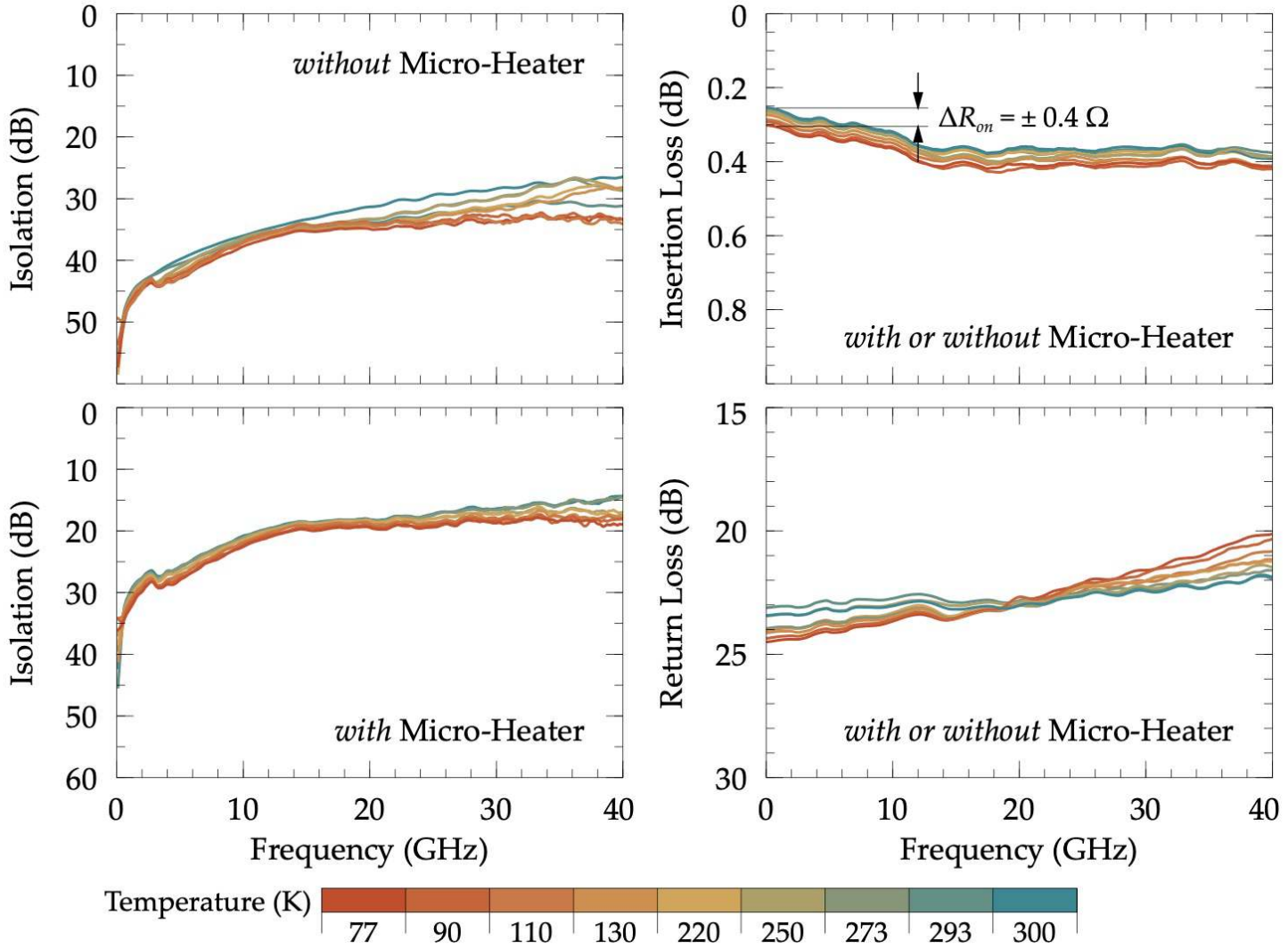
Device Cycling at 77K

- Measured device resistance at 77 K over 100 pulse cycles, no failure or missed actuation between amorphous and crystalline pulse.
- Initial amorphous resistance is 10^11 and dropped by 1 magnitude because of compound thermal buildup.



Device Cycling at 77K

- Stable RF performance with minimum variations.
- ON-state resistance variation is under ±0.4 Ω only.
- Isolation improvement is minimal with the microheater because of the prominent OFF-state capacitance but devices without micro-heater shows improved isolation.



Summary

- **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
- RF and DC performance of the phase-change switches is investigated at cryogenic temperatures.
- Operating the switches are cryogenic temperatures demonstrate high ON/OFF-state resistance with more than 10 orders of magnitude change.
- RF performance remains stable over a wide temperature range.

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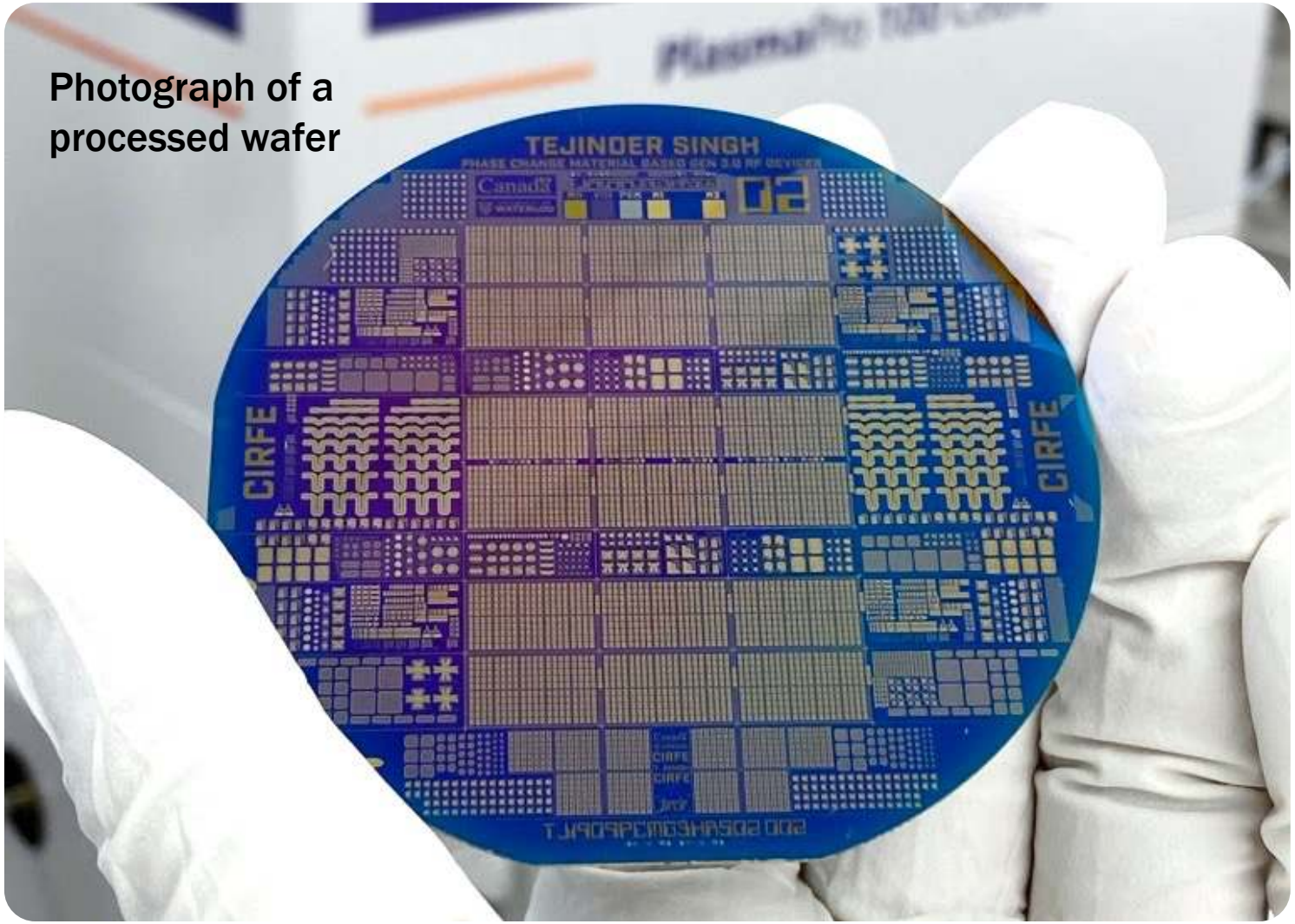
THANK YOU!



Photograph of a processed wafer

Forward your questions to

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