Micro-machined High Density Embedded Capacitor Technologies for Energy Storage Applications

by

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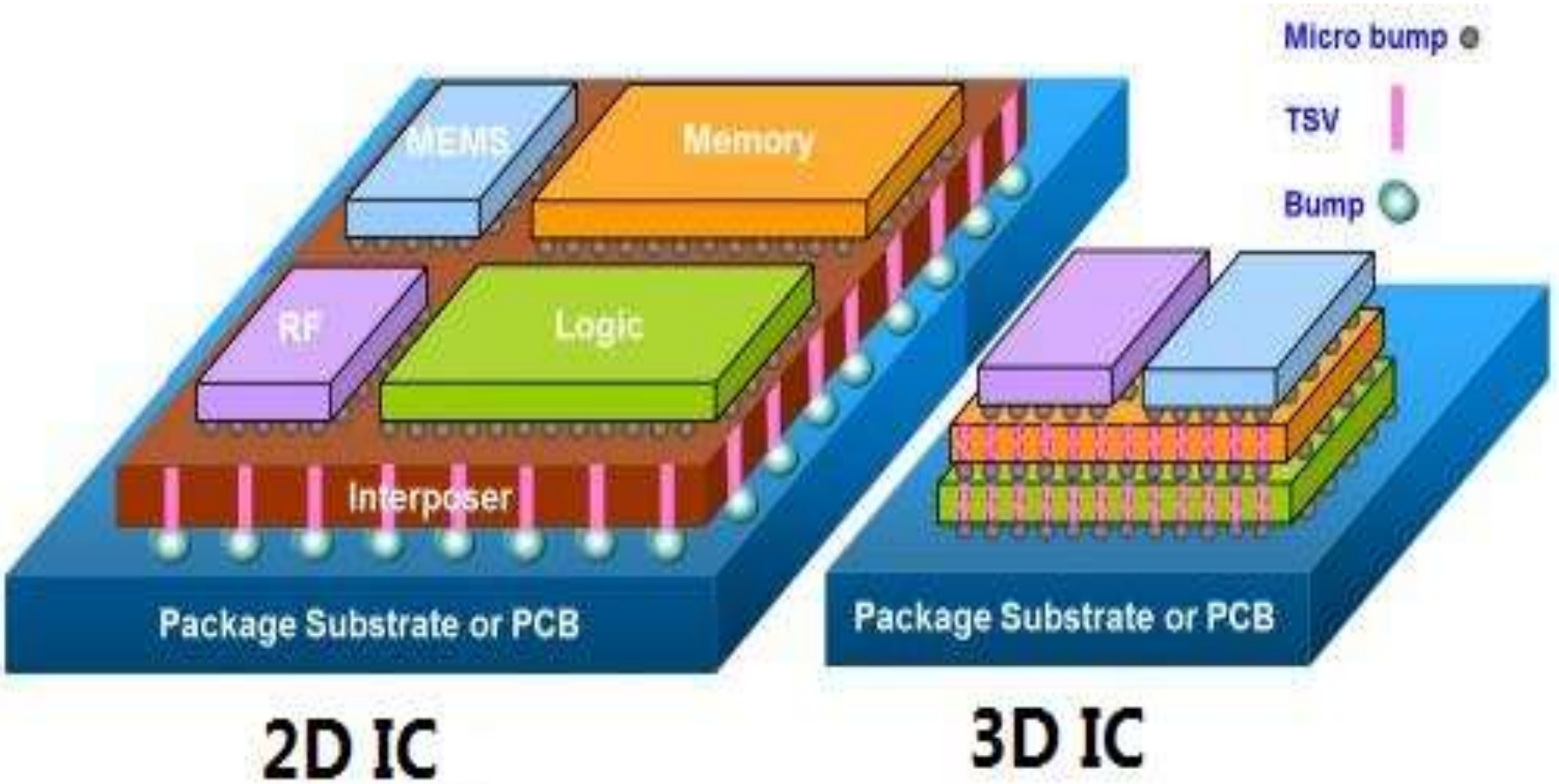
MEMS Super Capacitors: Application

- Substrate embeddable to provide current to circuits during power anomaly (i.e. Interposer)
- Requires low inductance path for rapid current discharge
- Requires etched cavities to increase surface area of capacitor

Interposer Provides Power Source Directly to Chips



Approach and Concepts

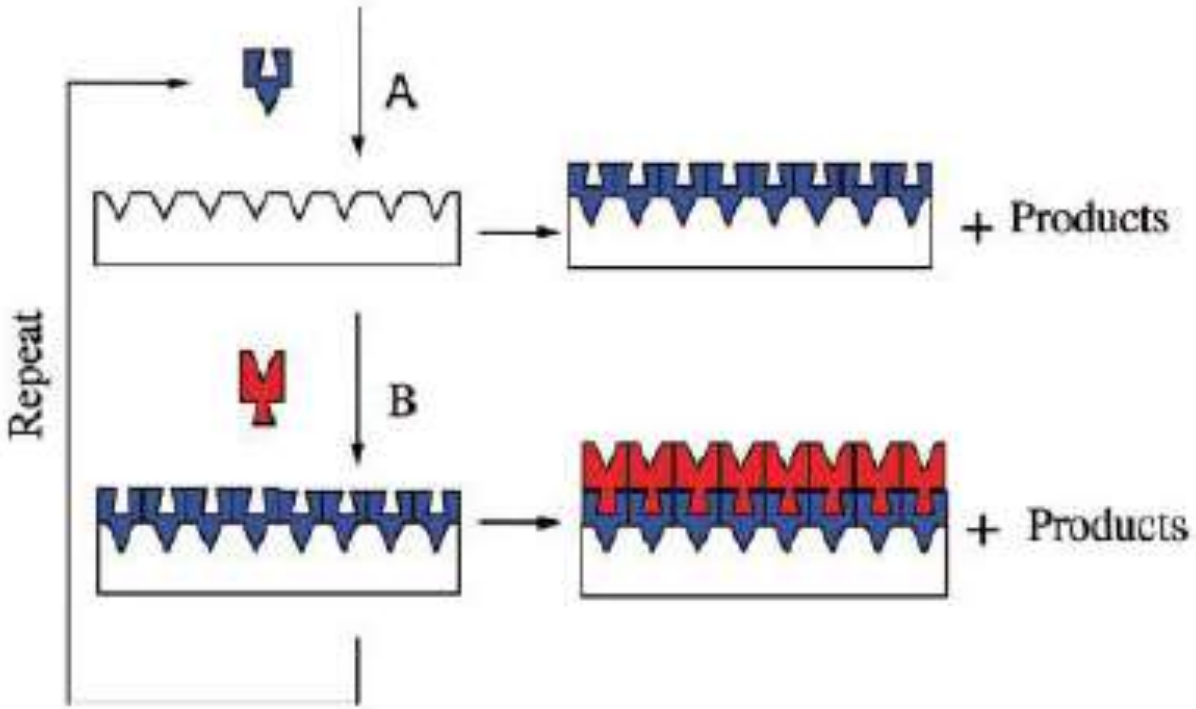
- Fabricate Planar Structure with SiO_2 (relative permittivity ~ 3.8)
- Fabricate Planar Structure with Atomic Level Deposition (ALD) HfO_2 (large relative permittivity ~ 25) from multiple vendors
- Fabricate Planar Structure with ALD HfO_2 and DRIE etched features
- Characterize Discharge Characteristics
- Summary

MEMS Super Capacitors: Fabrication

- n-type <100> silicon wafers
- Oxidized in steam/dry O_2 @ 1050˚ C for

  1- 4 hours $0.15\mu m < t_{ox} < 0.8\mu m$
- Top side selectively DRIE etched (increase surface area) and selectively doped
- Atomic Level Deposition performed
- Metalized with 100nm Ti /0.4µm of Cu

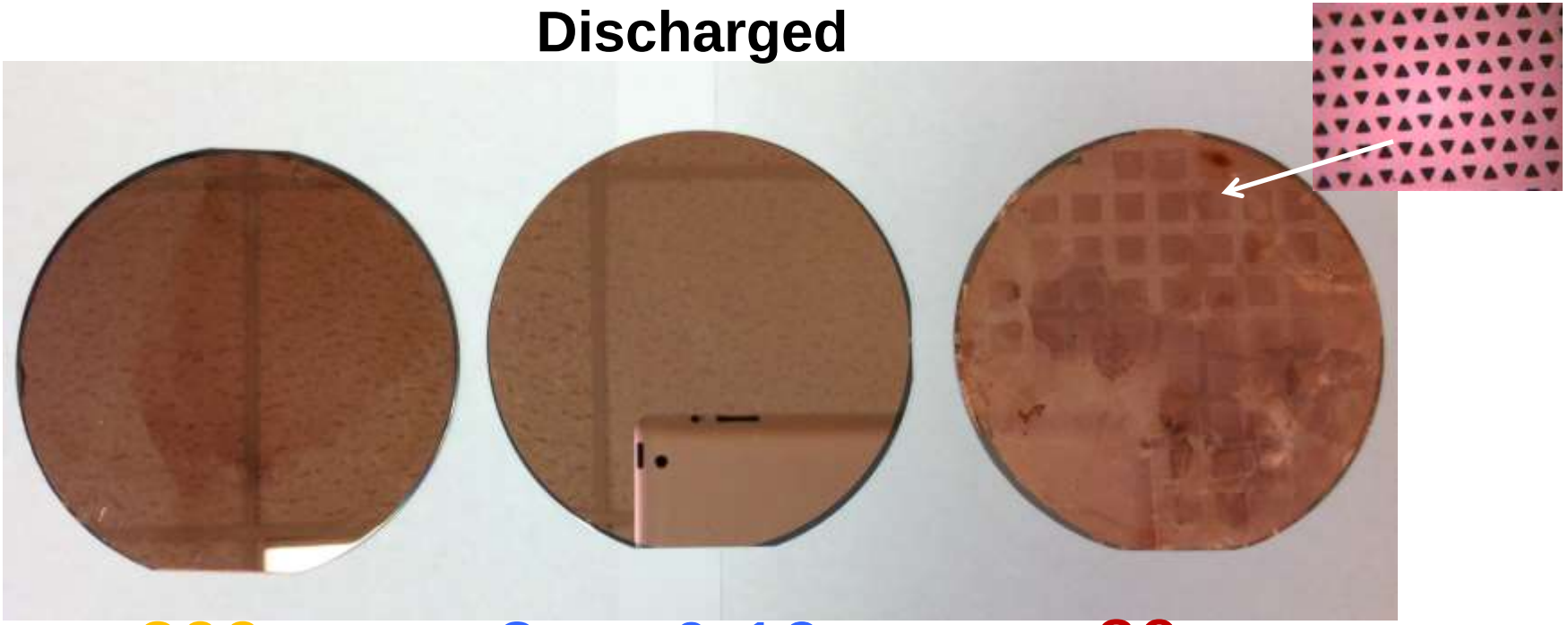
Basic Atomic Level Deposition Process



Interposer Capacitor 100 mm Silicon Test Wafers

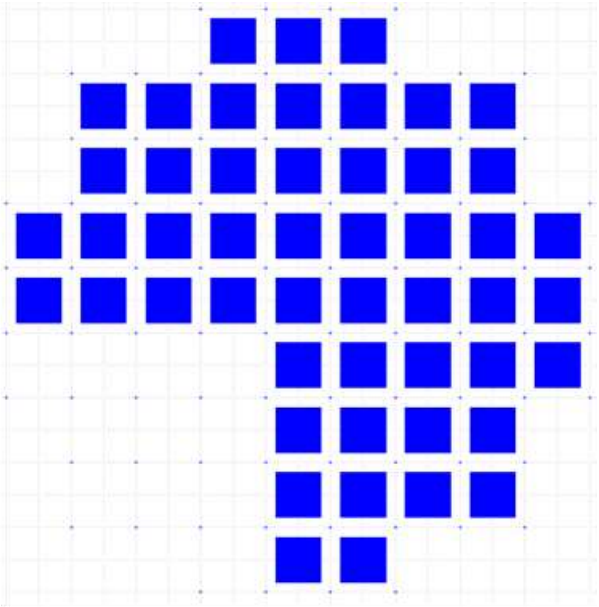
Thermal SiO_2 ALD HfO_2 GIT ALD HfO_2 Cam. Nano.

All Samples Initially Charged to 2V and then Discharged

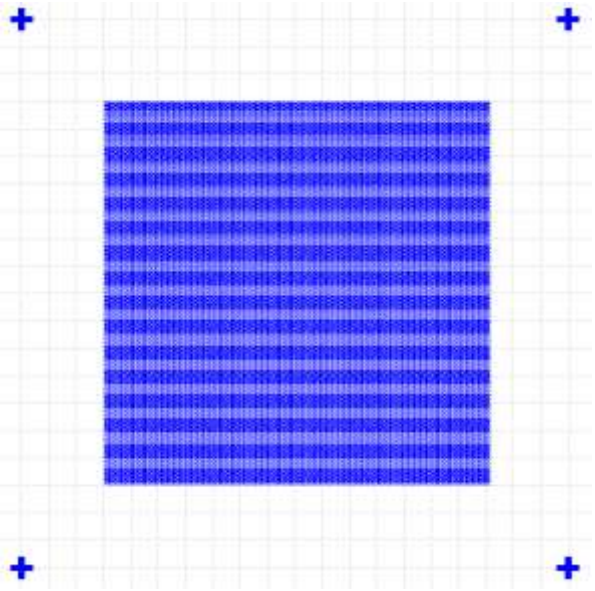


800nm 3nm & 10nm 30nm

MEMS Super Capacitors: Micromachining Pattern

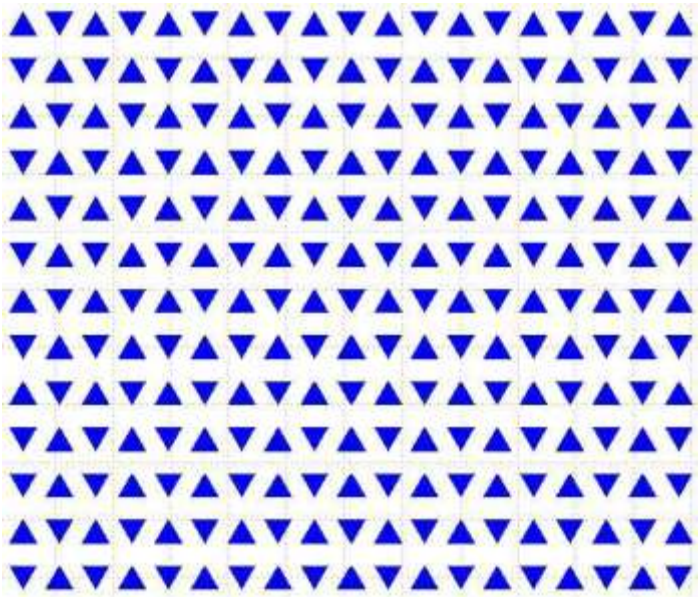


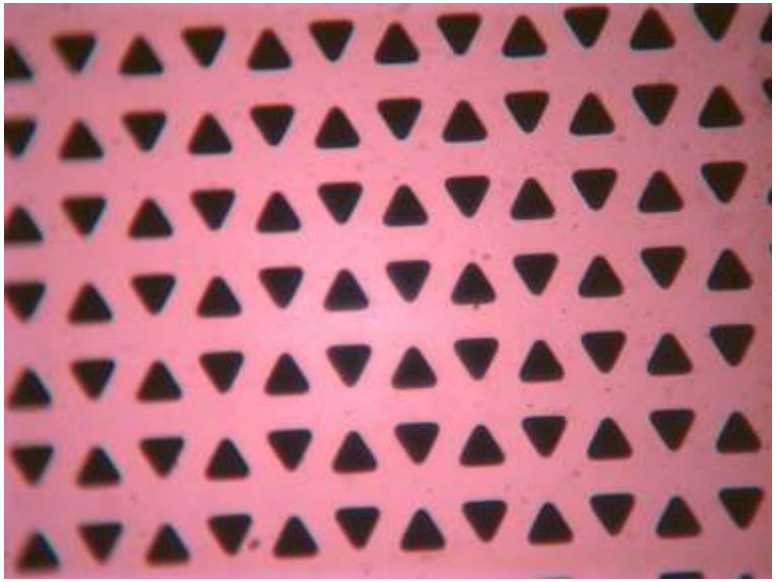
Layout of Wafer



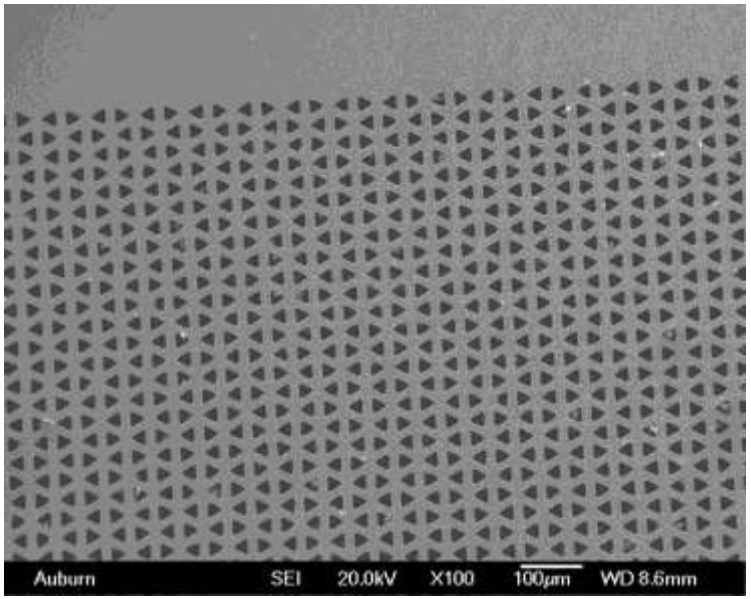
Layout of Individual Chip

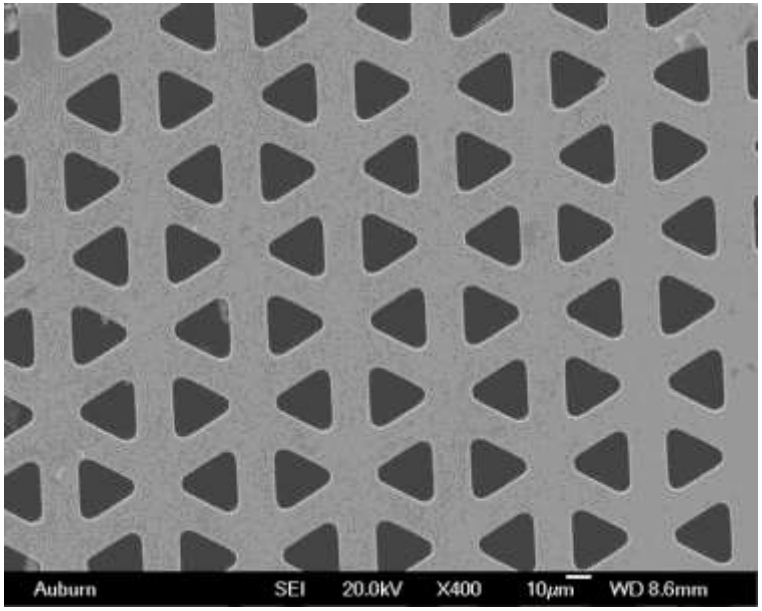
Cylinder and Triangle Pattern Utilized

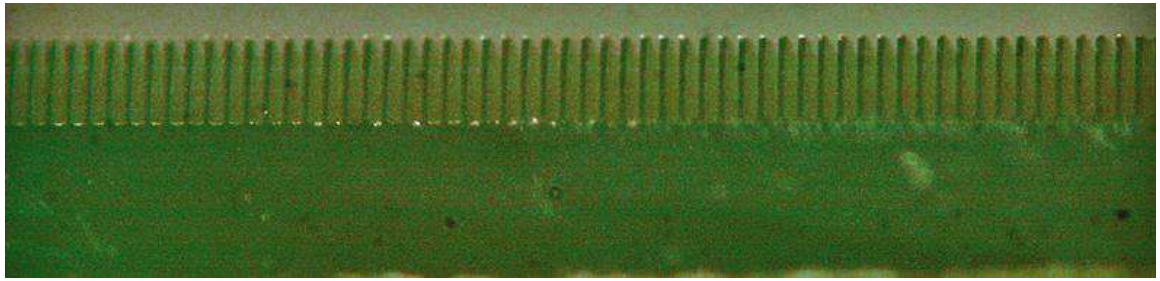




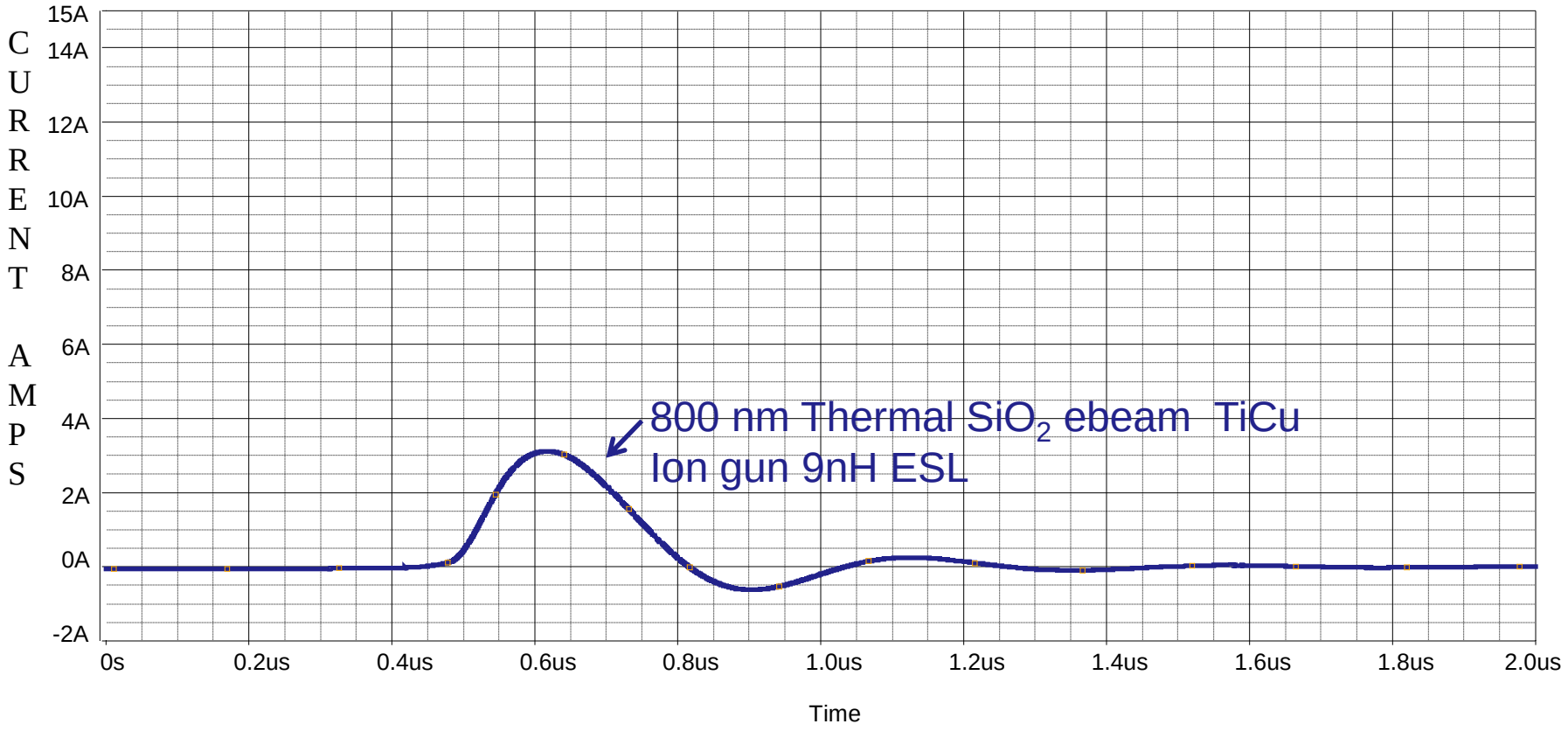
SEM & Photo Micrographs of DRIE Etched Features



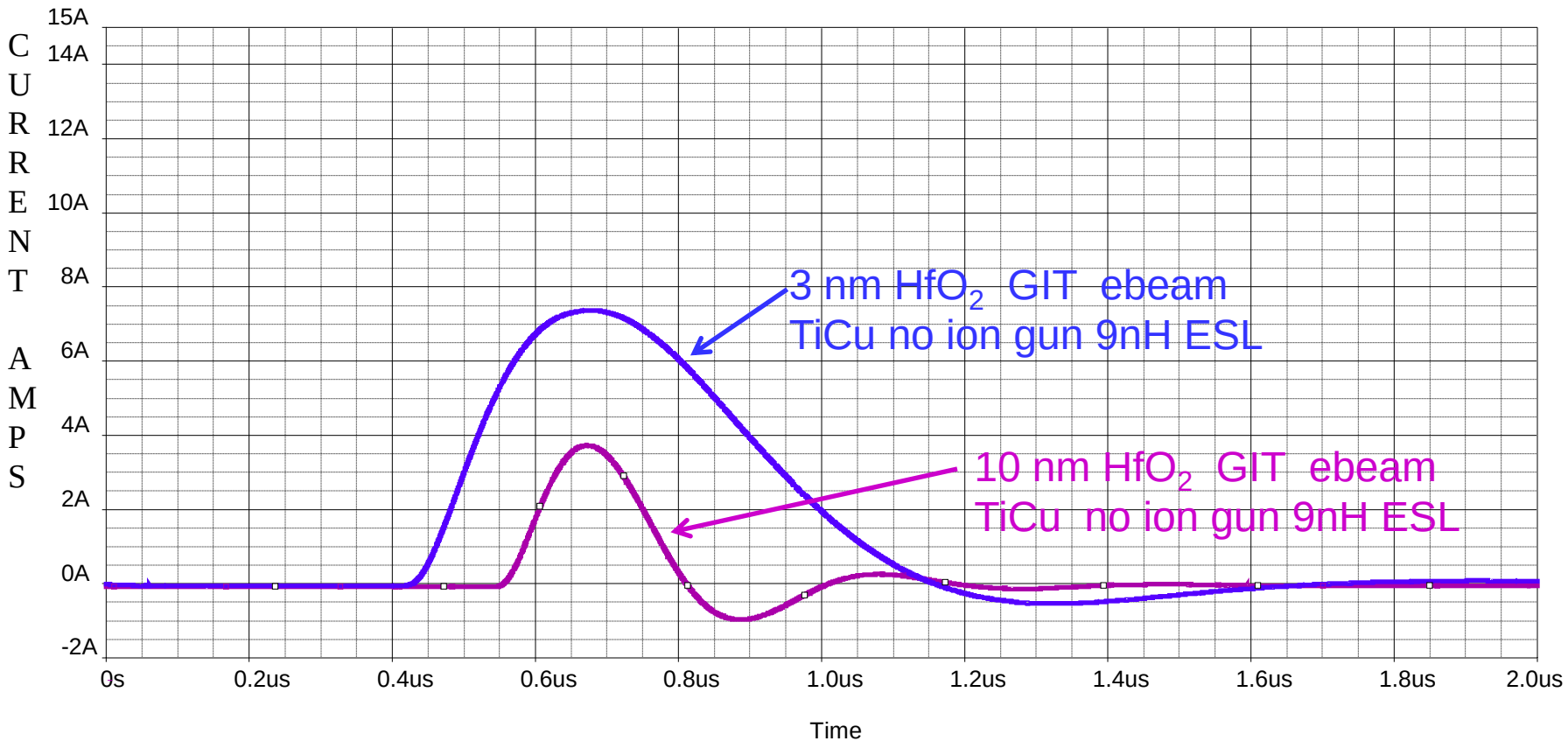




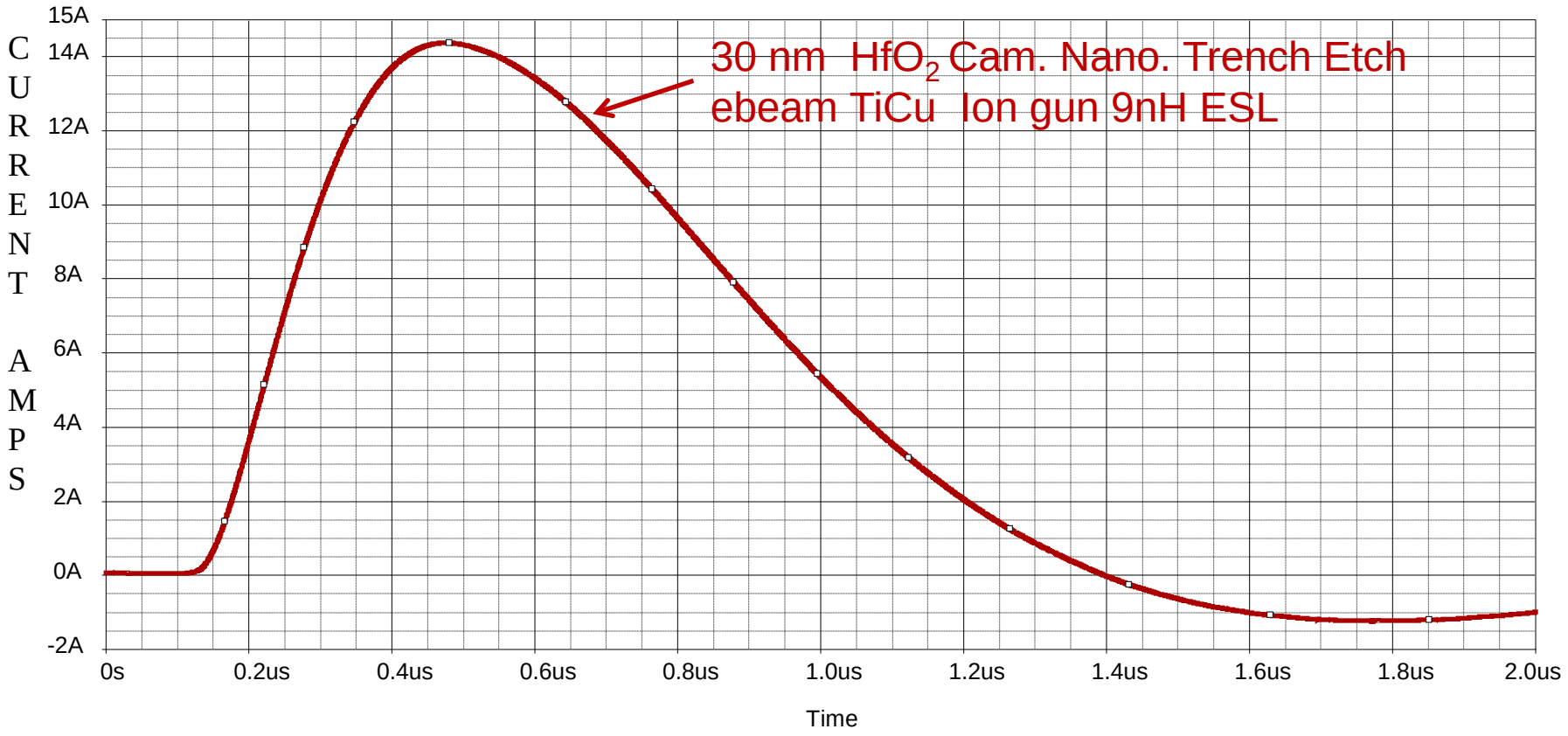
Thermal SiO_2 E-beam TiCu



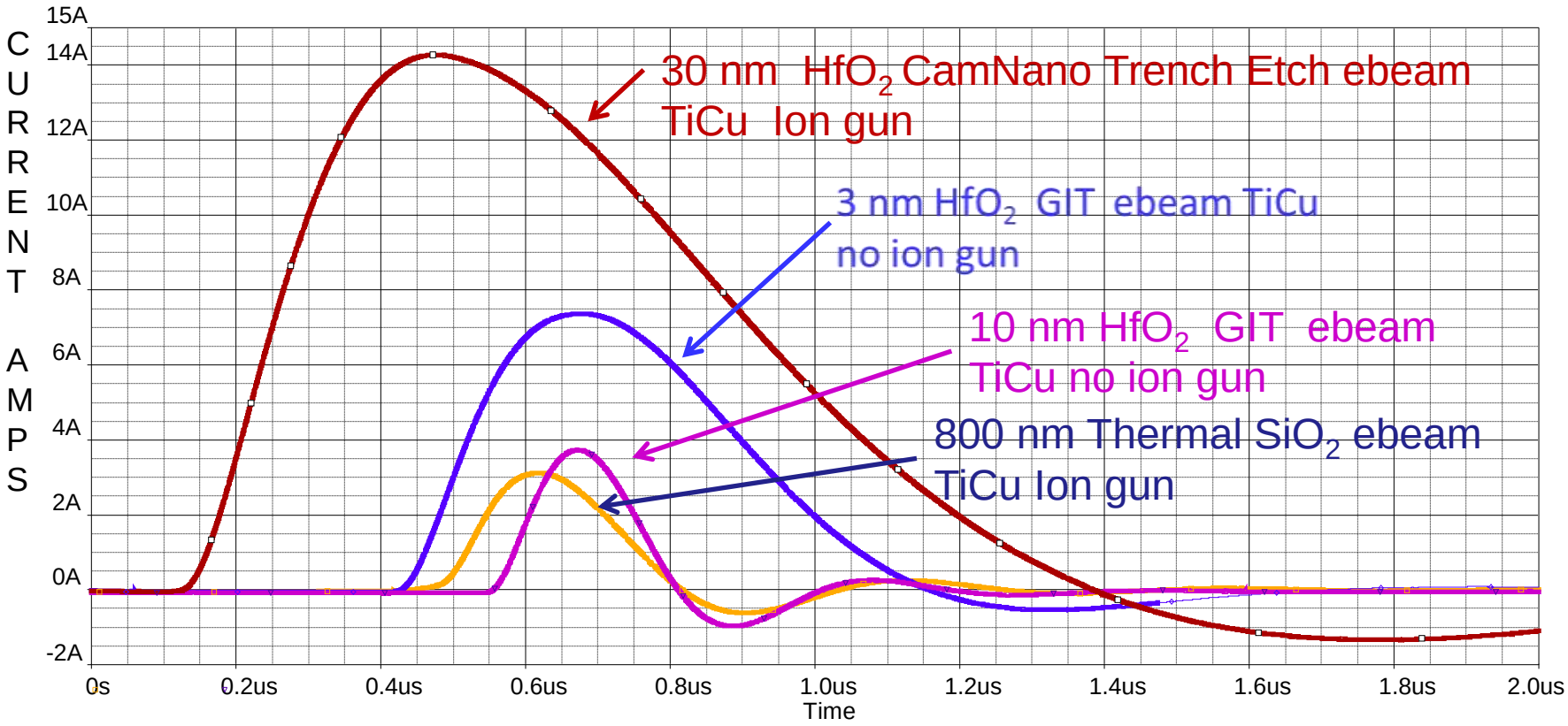
ALD HfO_2 GIT E-beam TiCu



ALD HfO_2 Cam. Nano. E-beam TiCu

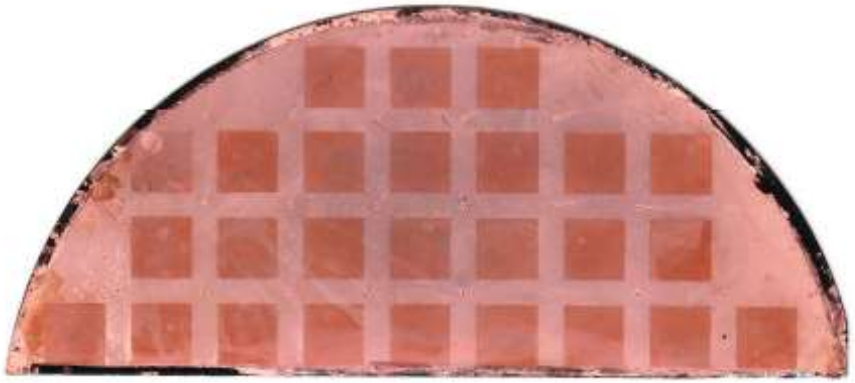


Composite


CURRENT AMPS
15A
14A
12A
10A
8A
6A
4A
2A
0A
-2A
0s
0.2us
0.4us
0.6us
0.8us
1.0us
1.2us
1.4us
1.6us
1.8us
2.0us
Time
30 nm HfO2 CamNano Trench Etch ebeam TiCu Ion gun
3 nm HfO2 GIT ebeam TiCu no ion gun
10 nm HfO2 GIT ebeam TiCu no ion gun
800 nm Thermal SiO2 ebeam TiCu Ion gun

Half Wafer HfO_2 Capacitor

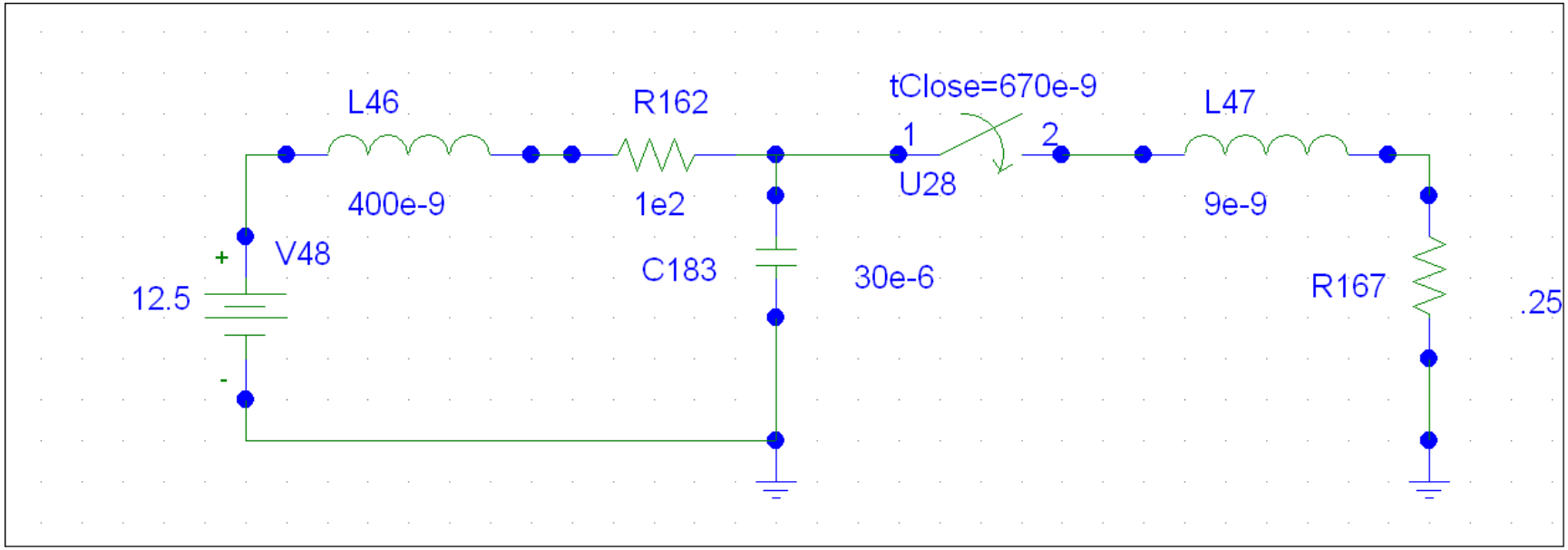
Sample Charged to 12.5V and then Discharged



$$C = (\varepsilon_R \varepsilon_o Area)/t_o$$

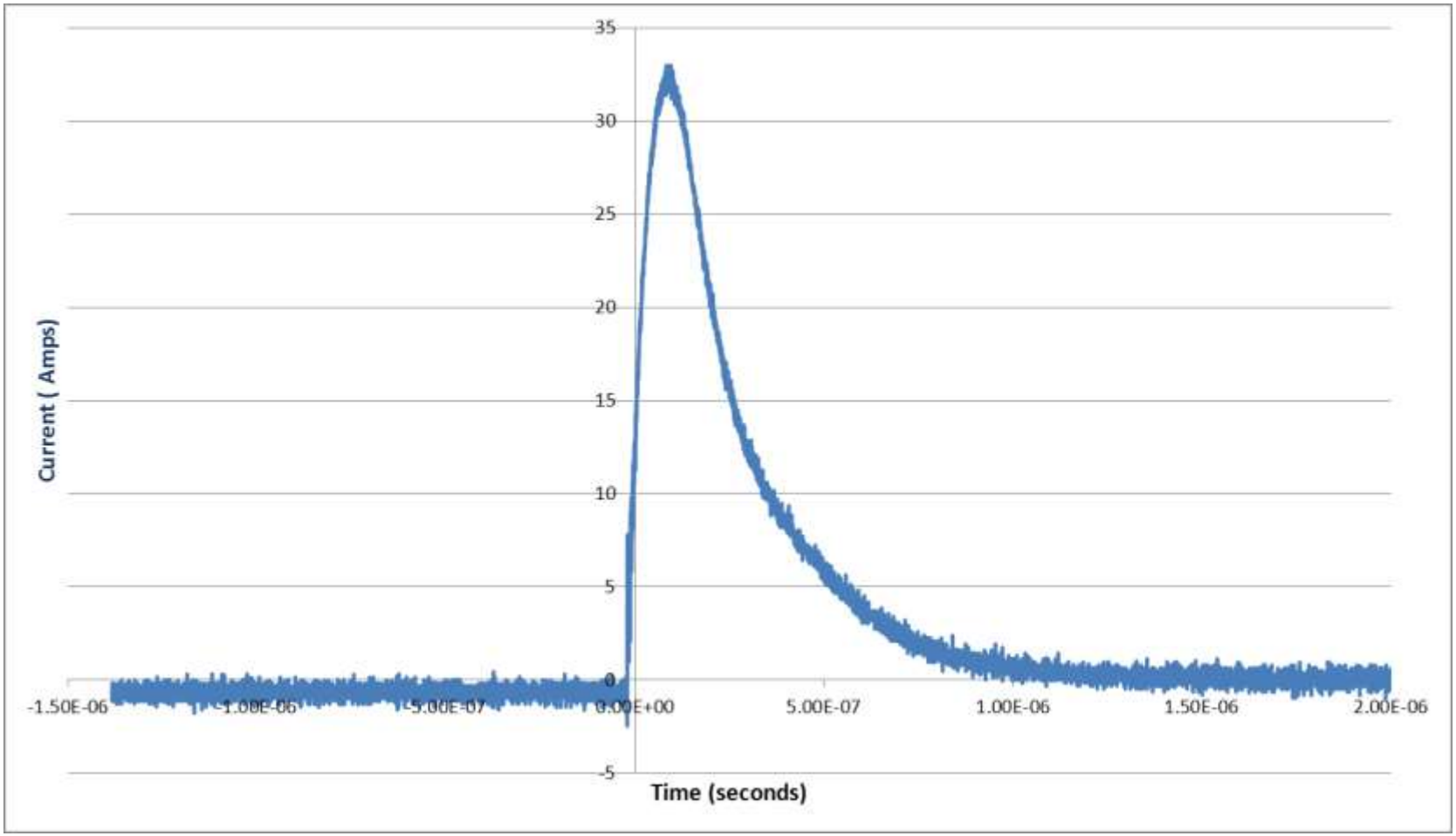
$$C \sim 30{,}000nF$$

Test Circuit for Half Wafer HfO_2 Capacitor: 9nH ESL



Ringdown in Time Domain

- 30nm thick hafnium oxide 30,000nF 12.5V discharge with an ESL = 9nH ESR = 0.25Ω



FFT of Ringdown

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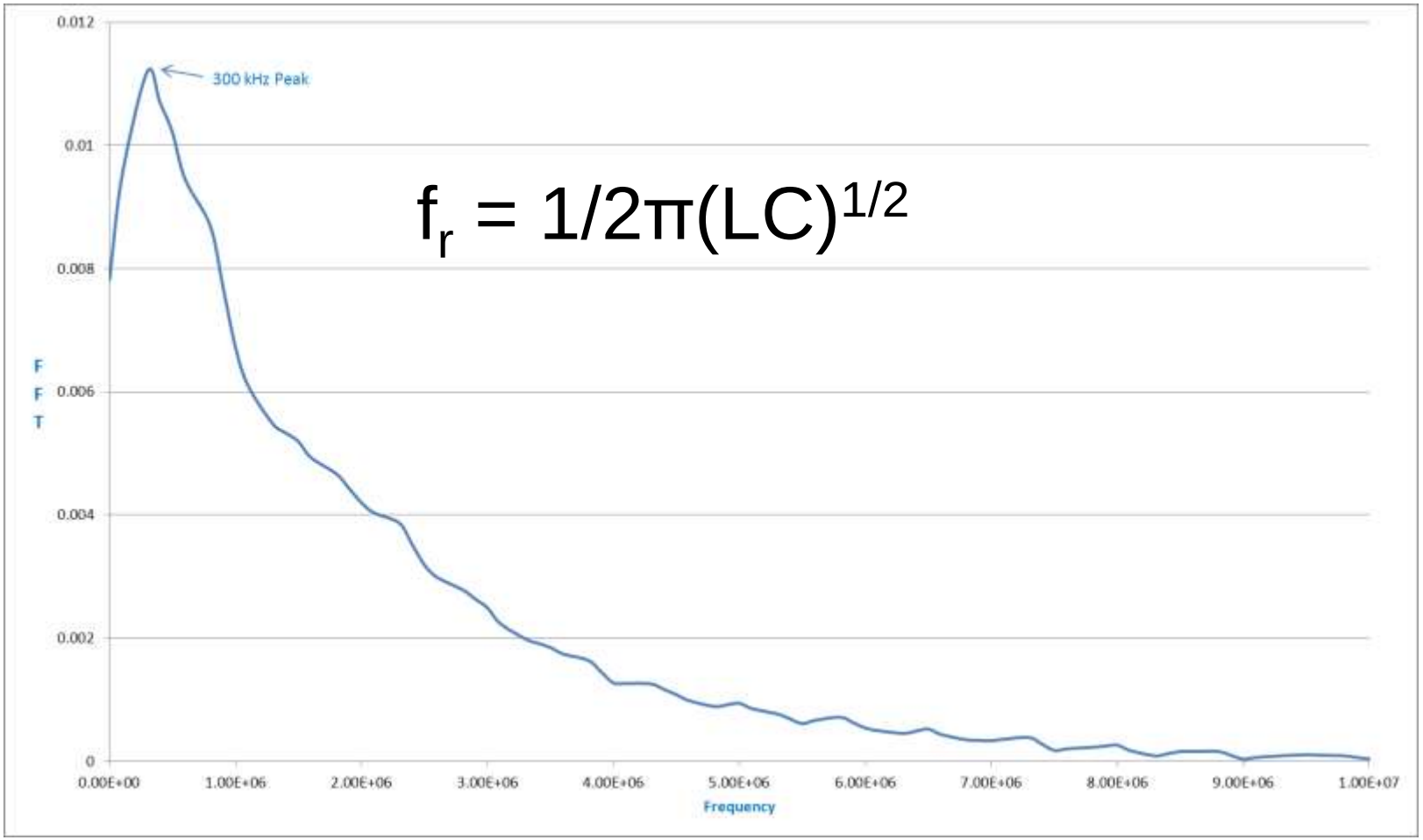
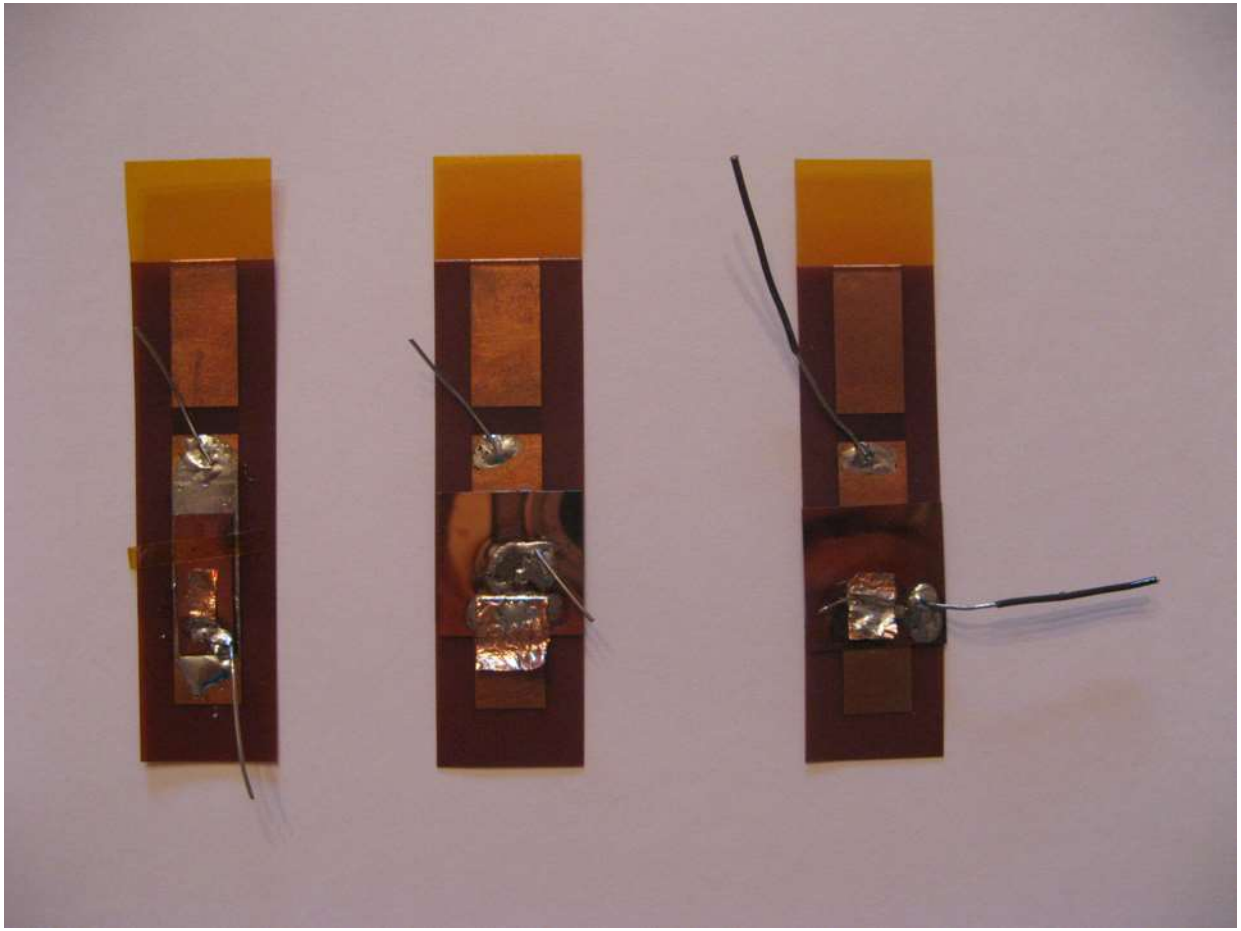


MEMS Super Capacitors: SPICE Modeling

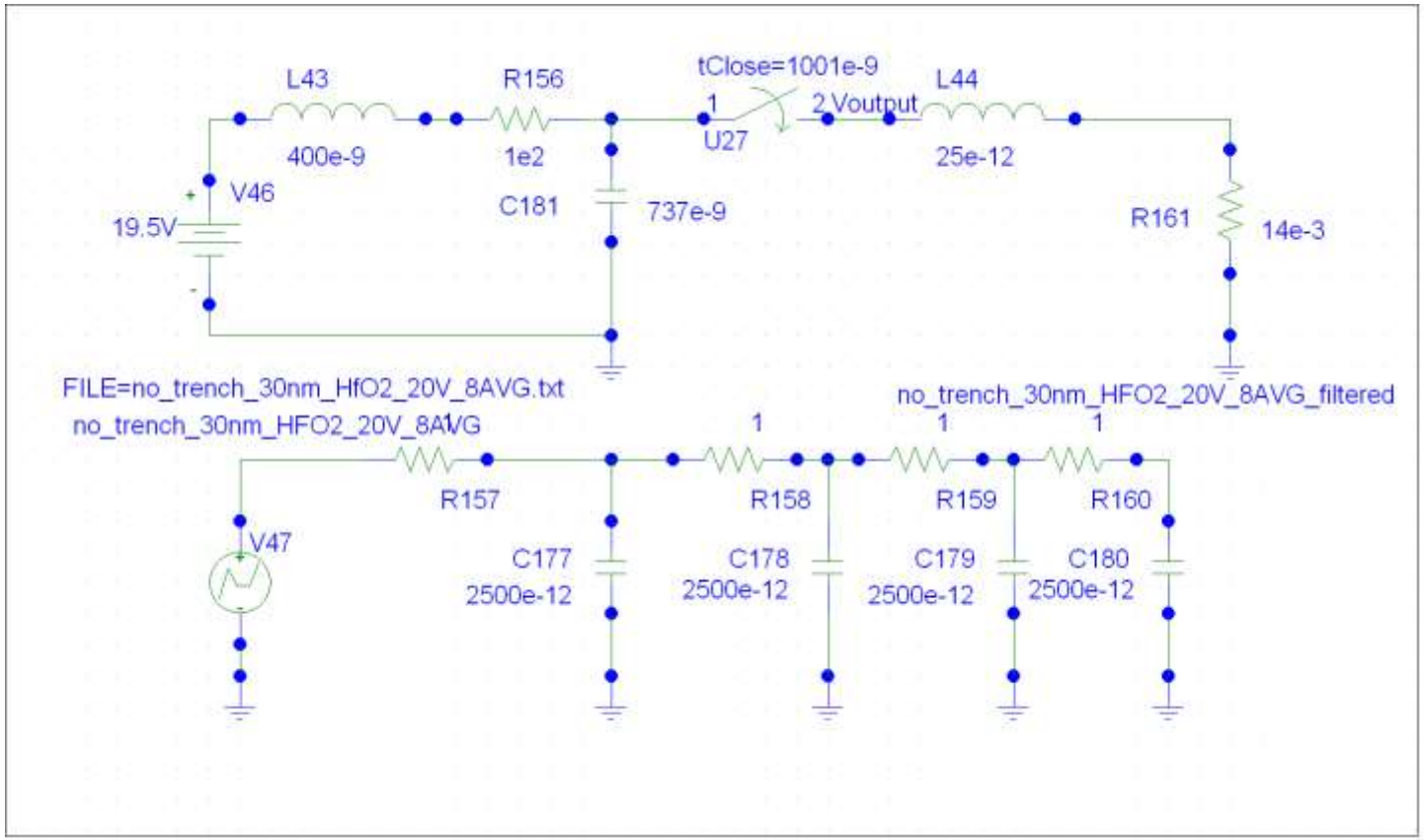
- High speed ringdown tests for a variety of configurations performed to determine capacitor performance under rapid discharge conditions
- Empirical data compared graphically to theoretical voltage discharge profiles
- Current discharge calculated from C(dV/dt)
- Results plotted and compared

MEMS Super Capacitors: Photos



PSPICE Model

- 30nm thick hafnium oxide capacitor C = 734nF, 19.5V discharge voltage with an ESL = 25pH ESR = 14mΩ



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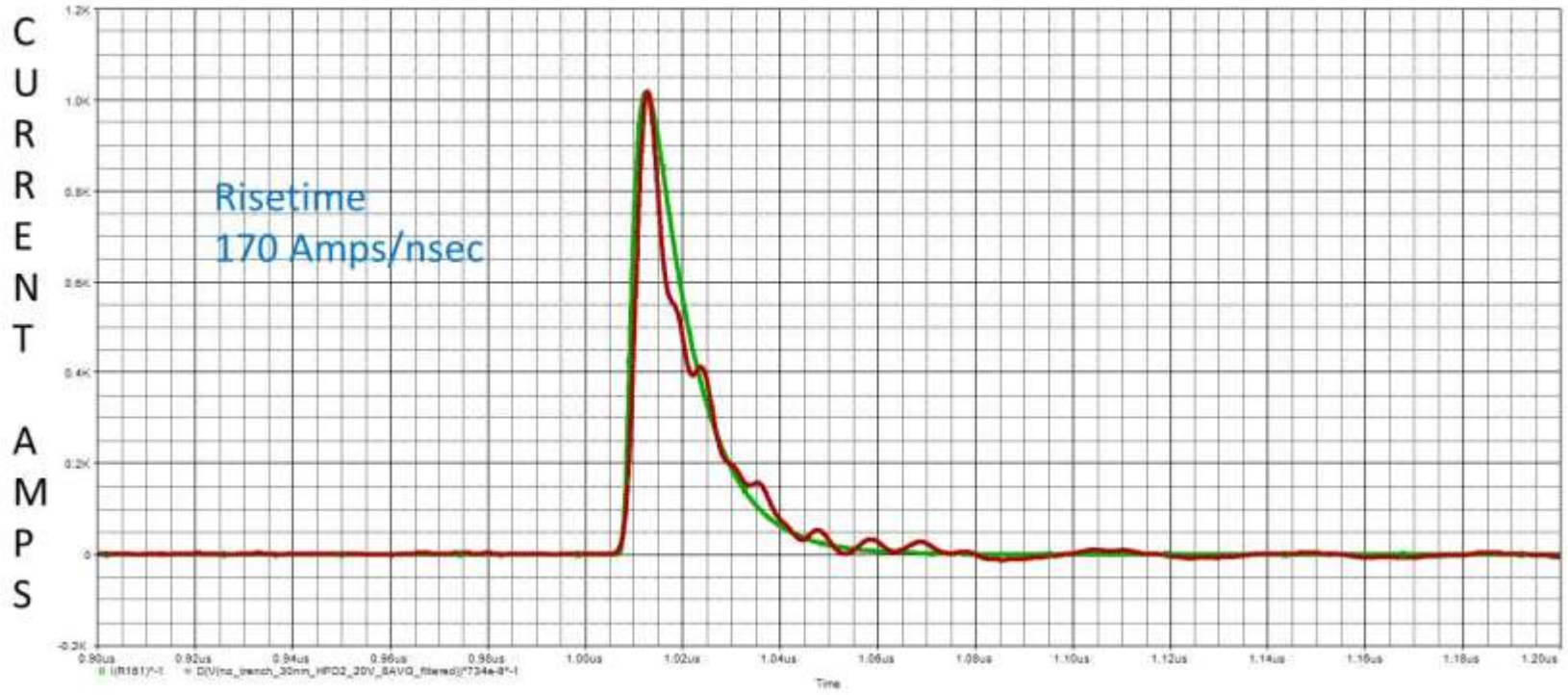

Summary

- Possible to fabricate high value capacitors for interposer
- Risetime dependent upon load
- HfO_2 has high dielectric constant (~25)
- SiO_2 is more readily available from silicon foundries