



GE AEROSPACE RESEARCH

UV Imaging Electronics and Packaging for Venus Mission

High Temperature Electronics Network (HiTEC) 2025
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Long-Life In-situ Solar System Explorer (LLISSE)

Mission Environmental Conditions

Goal: Transmit temperature, pressure, wind velocity and direction, and chemical composition every 8 hours (or better) over the duration of a day-light period including sun rise and sun set (preferred), operating for approximately 60 Earth days.

Temperature: 460-480°C

Pressure: 8.9MPa, 1.305kpsi, 88.8 atm

Atmosphere: supercritical 96.5% CO₂, 3.5% N, 0.015% SO₂, HF (2.5 ppb)

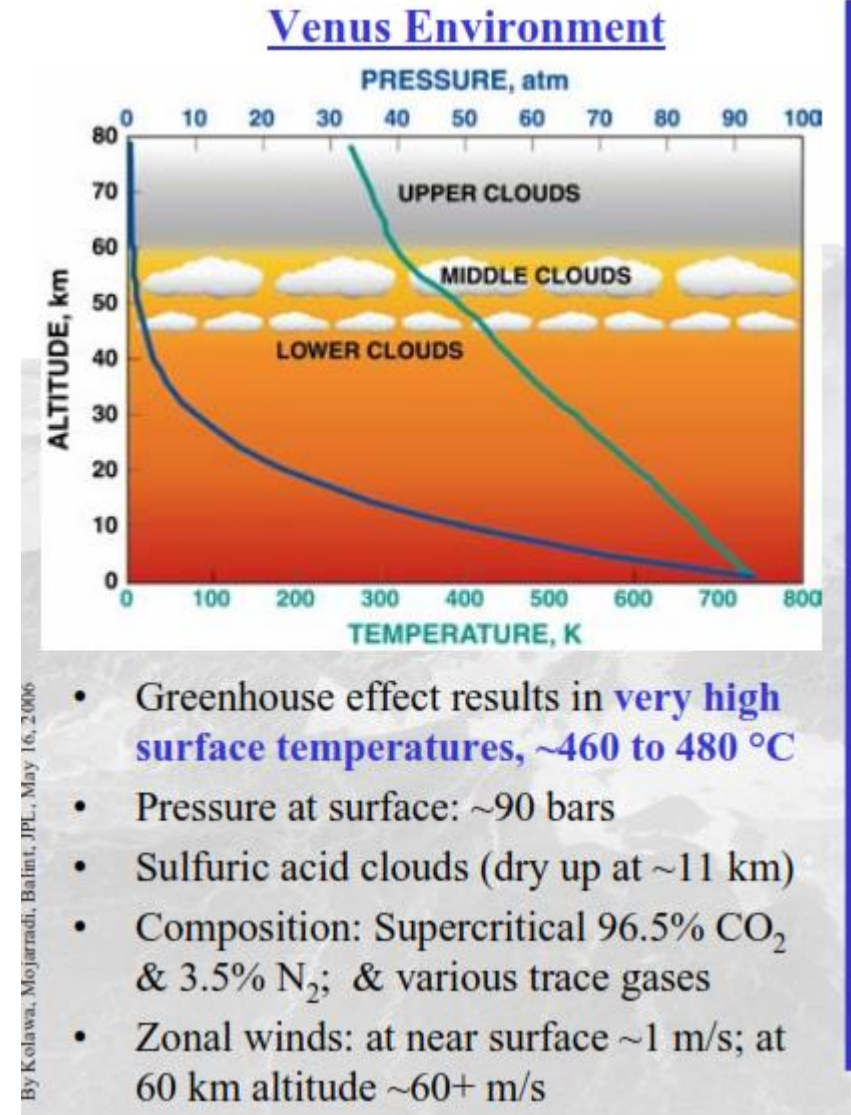
Transmit frequency: 100 MHz to orbiter 70Mm above surface

Venus day (Earth time): 116 days, 18 hours, 0 mins

Venus sidereal day: 243 Earth days

Venus year: 224 Earth days

46 missions to Venus, 22 successful. Longest time: 127 minutes (Wiki)



GEER Venus Environment Test

Glenn Extreme Environment Rig (GEER)

Temperature: 460°C ($\pm 2^\circ\text{C}$)

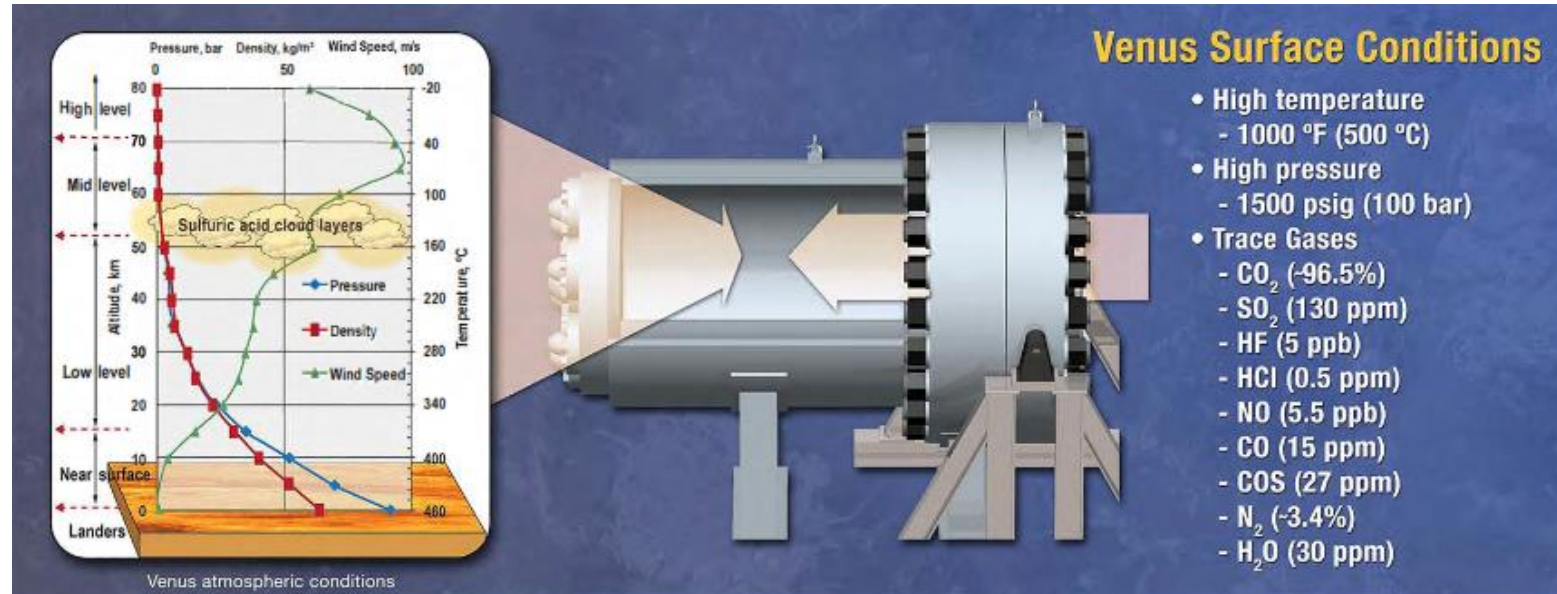
Pressure: 1344 psia (± 15 PSI)

Gas Chemistry:

Phase 1: N₂ only

Phase 2: Standard Venus mix – 96.5% CO₂, 3.5% N₂, 180 ppm SO₂, 12 ppm CO, 51 ppm OCS, 2 ppm H₂S, 0.5 ppm HCl, 2.5 ppb HF, 30 ppm H₂O

Duration: 10 earth days. The sample was submitted twice.



The photos are courtesy of NASA Glenn Research Center. <https://www1.grc.nasa.gov/space/geer/geer-for-venus/>



NASA GEERS

Candidate materials previously tested to withstand 500°C were compared to Lukco. Lukco reported structural materials reacting to a simulated Venus condition (GEER).

Candidate material elemental composition was measured using ICP-OES.

Gold materials had potential for Venus. Dielectrics contain Ca and Zn that may form sulfide and/or sulfide. Zn may oxidize.

Candidate materials were prepared for GEER testing. The sample was exposed to 2 cycles.

Material	Use	Au	Al	Ba	Ca	Co	Cu	K	P	Pb	Zn	Zr
Au Conductor (C1)	Circuitry	99.5	0.0380	<0.0005	<0.001	0.0056	0.176	<0.001	<0.002	0.70	0.48	0.167
Dielectric1 (D1)	Xover/Pass.	<0.001	16.8	7.34	6.99	0.87	<0.002	<0.02	0.440	<0.01	15.8	1.230
Dielectric2 (D2)	Xover/Pass.	NA	3.28	15.6	2.00	0.379	<0.0005	0.173	<0.003	<0.004	9.16	1.758
Pure Au conductor	Die attach	101.0	<0.001	<0.0005	<0.001	<0.0005	<0.001	<0.001	<0.002	<0.003	<0.002	<0.001
Au Sintering Paste	Die attach	100.3	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.005	<0.002	<0.0005	<0.0002	<0.0002
Au bonding wire	Interconnect	101	<100	<20E-4	<400E-4	<20E-4	<20	<200E-4	<500	<50E-4	<20E-4	<10E-4

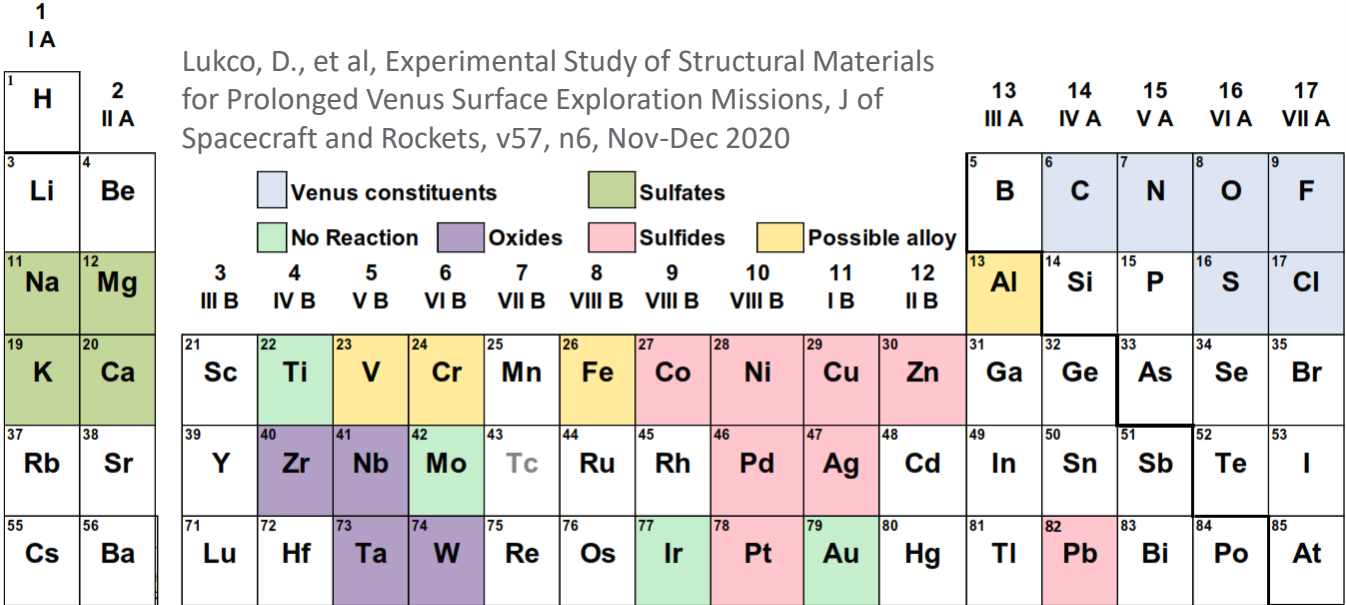
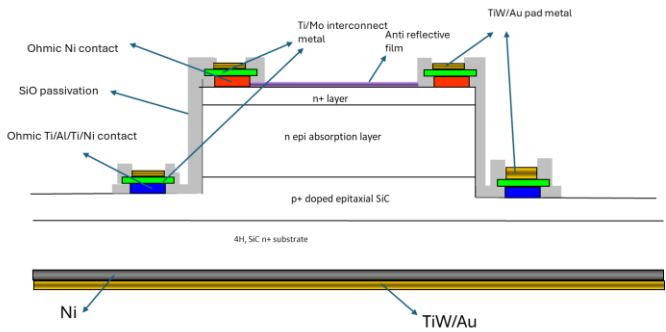
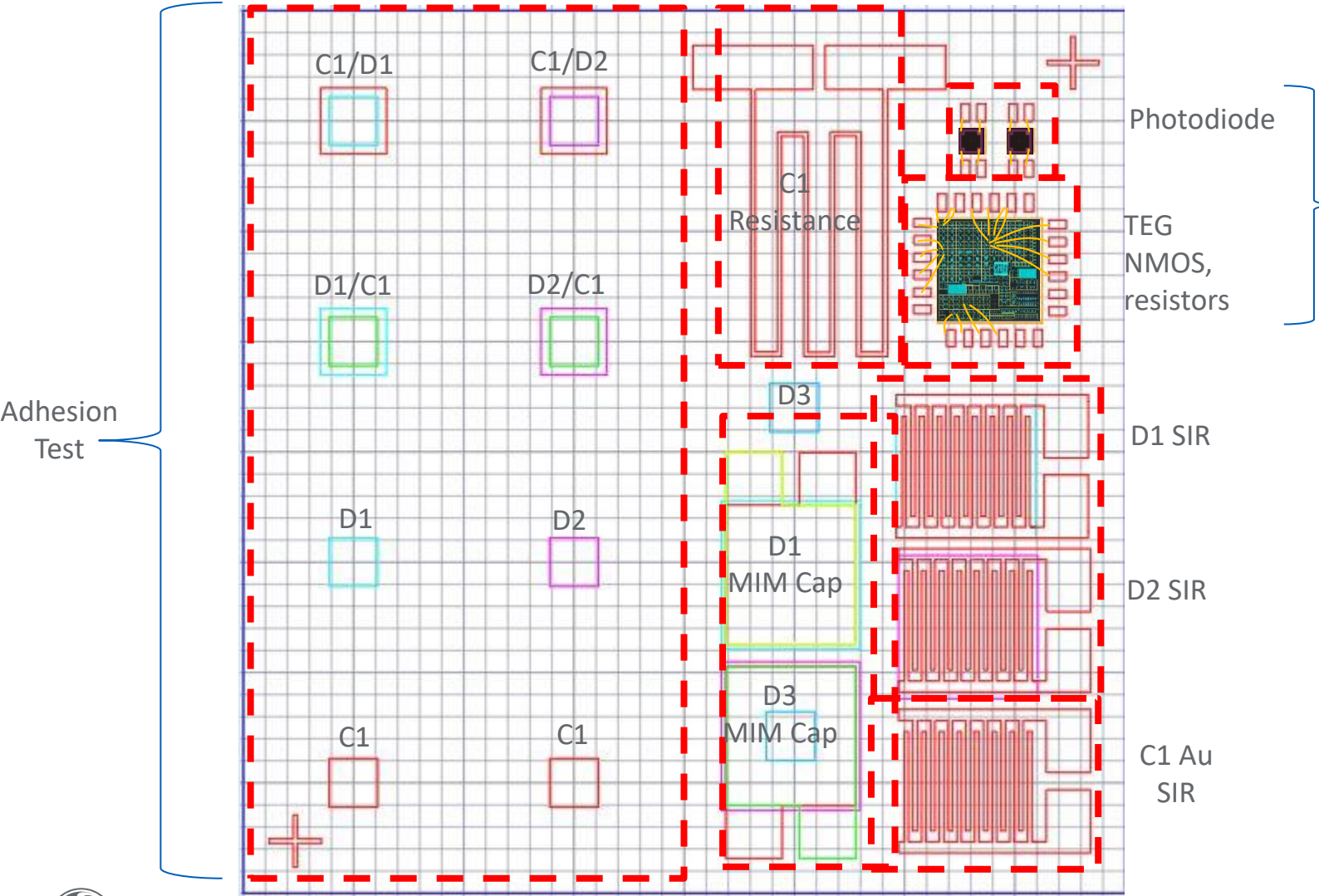


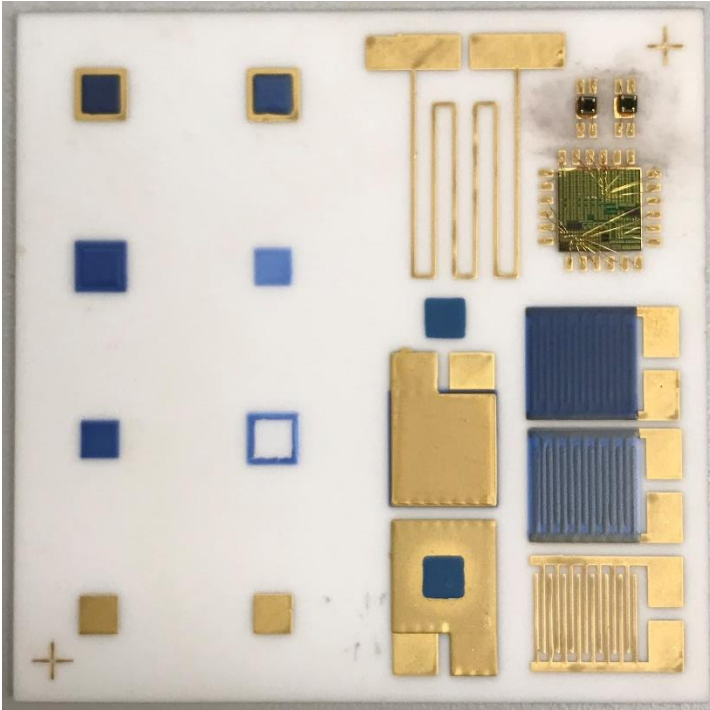
Fig. 13 Partial periodic table of elements tested in Venus surface conditions.



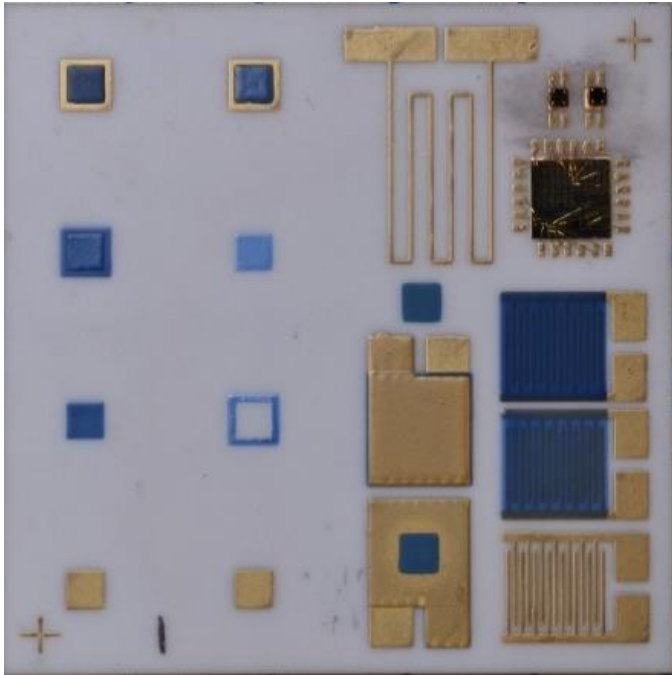
GE GEER Test Coupon



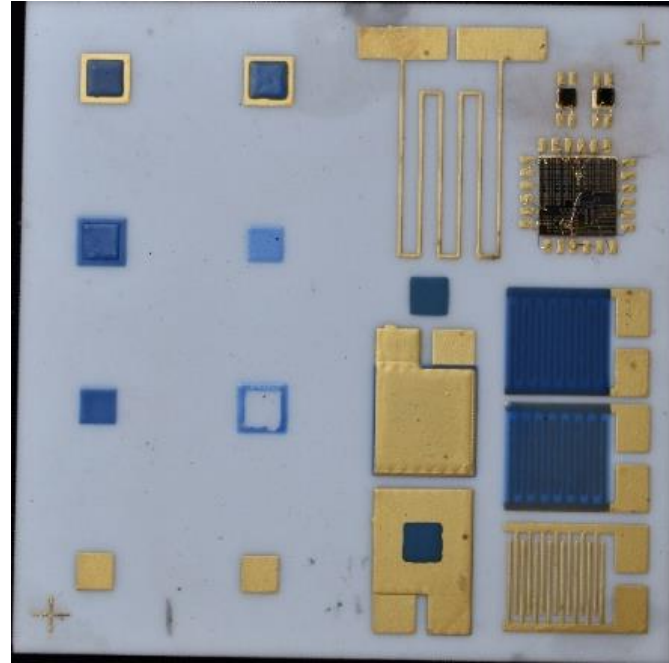
- Au paste Die Attach
- Au wire bonded



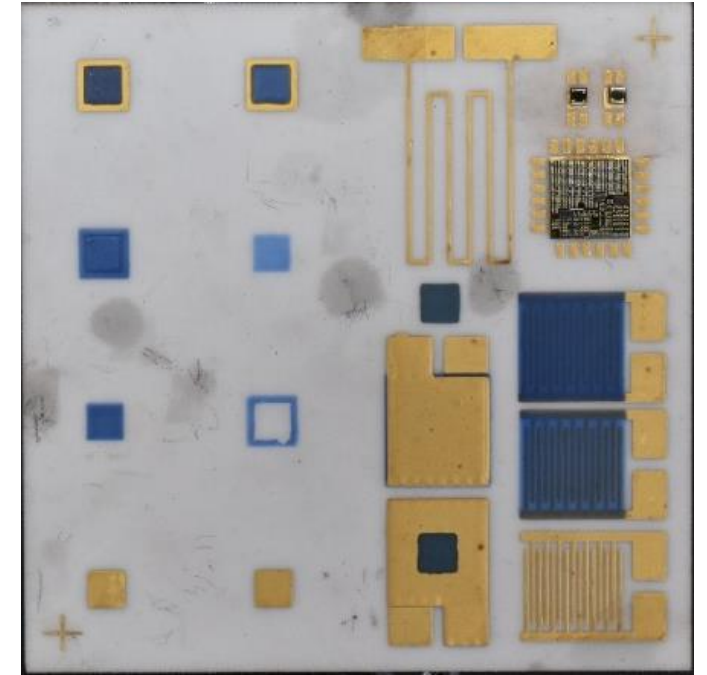
NASA GEER Test: Substrate Pictures



Before NASA GEER



After 1st NASA GEER



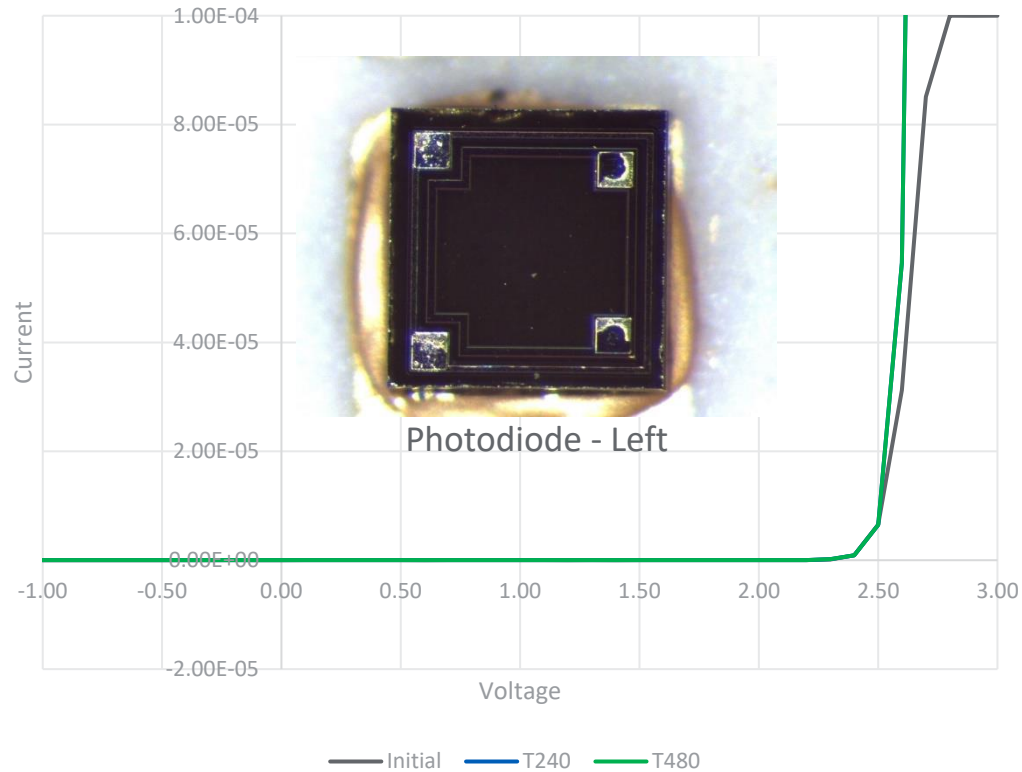
After 2nd NASA GEER

Packaging materials had survived and devices functioned electrically. However, wire bonds became unbonded from the devices after exposure to GEER. This indicated an alternate metallization needed.

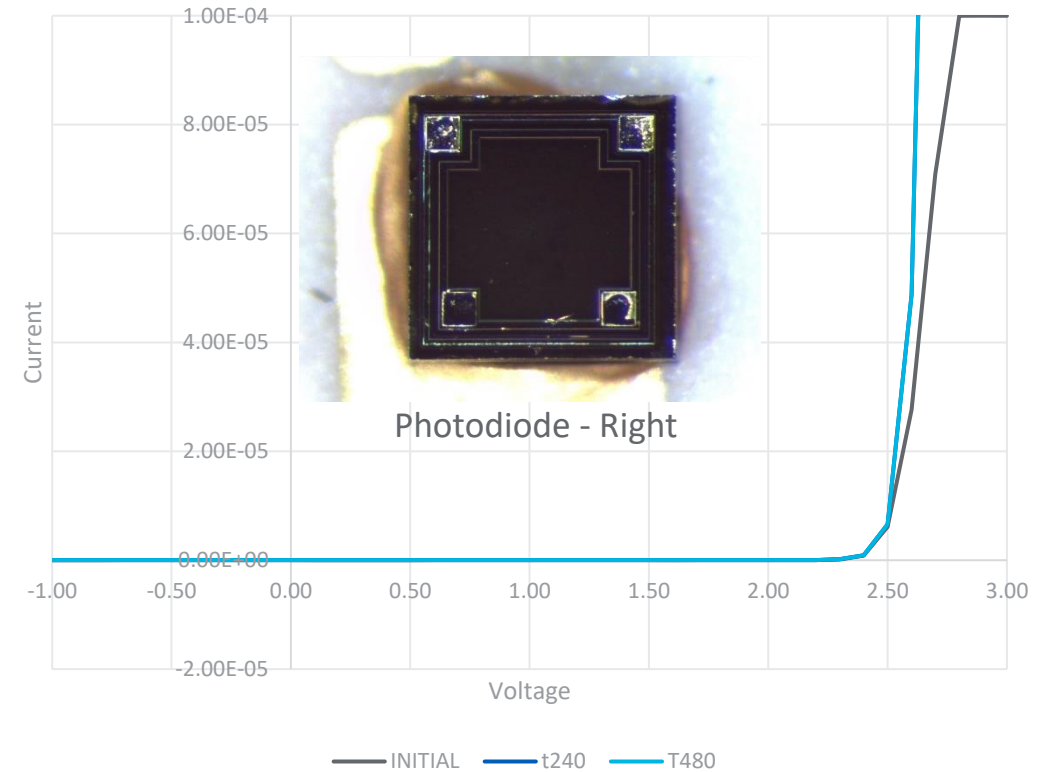
After the first GEER test, the substrate was GEER tested again since the packaging materials and device functionality was not degraded.

Post GEER Test Electrical – GE SiC Photodiodes

SiC Diode (Left) GEER TestT0,T240,T480

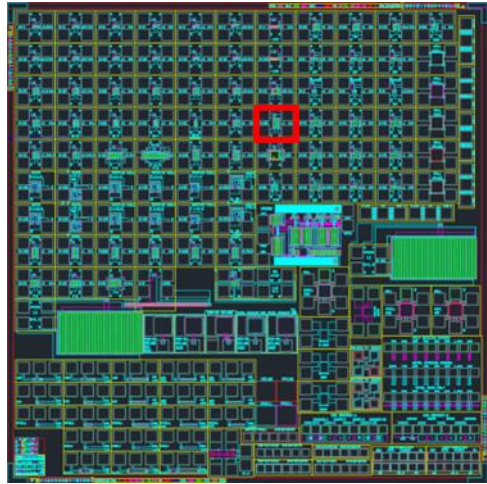


SiC Diode (Right) GEER TestT0,T240,T480

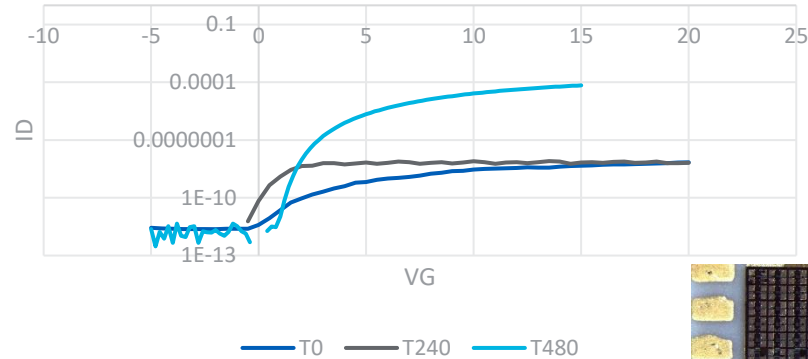


GE SiC photodiode remained functional after 2 GEER tests.
IV changed after 1st GEER test but not after the 2nd GEER test.

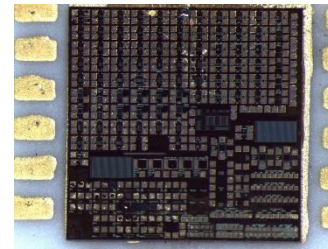
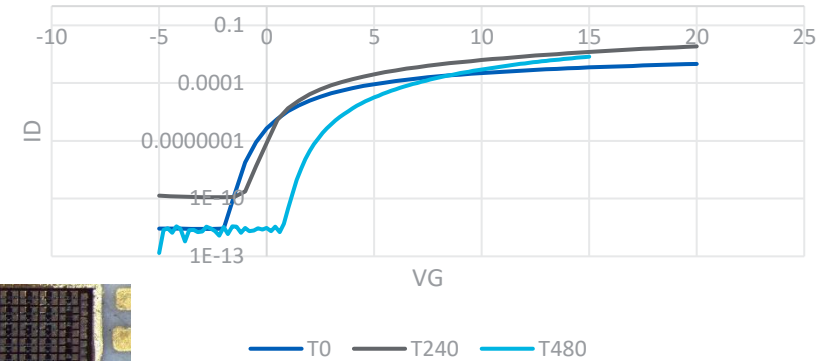
Post GEER Test Electrical - WX032 LMOS



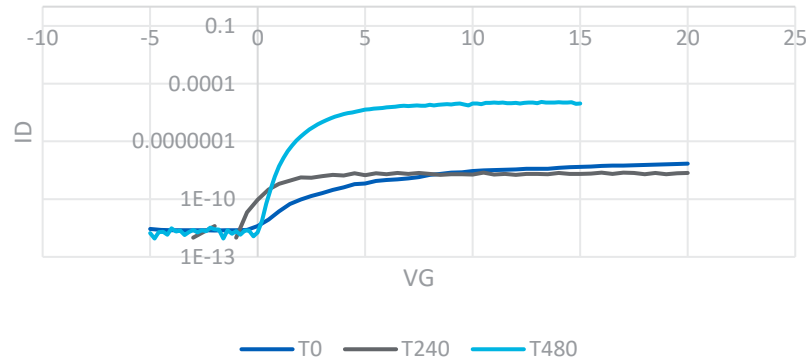
SiC LMOS W100L1 VD=0.1V



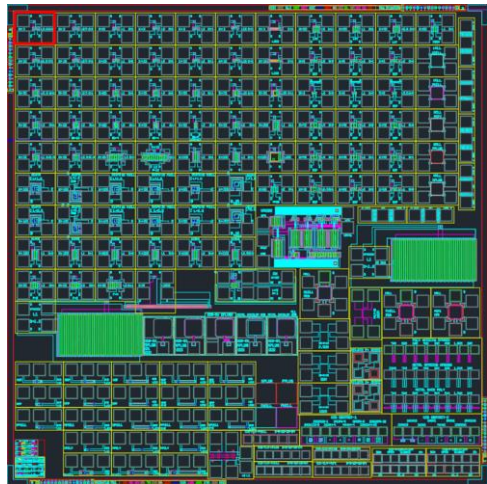
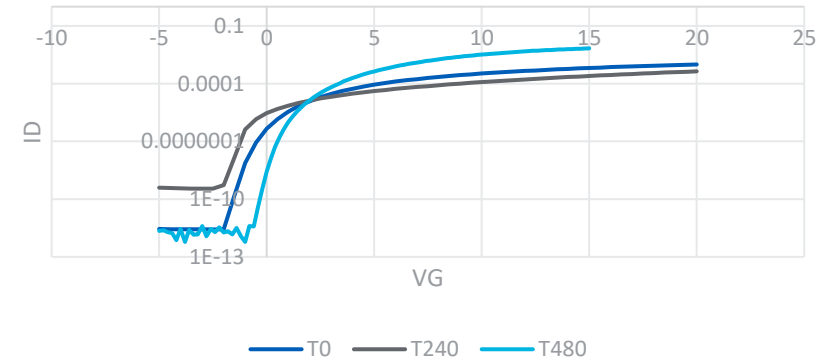
SiC LMOS W100L1 VD=15V



SiC LMOS W3L0.5 VD=0.1V



SiC LMOS W3L0.5 VD=15V



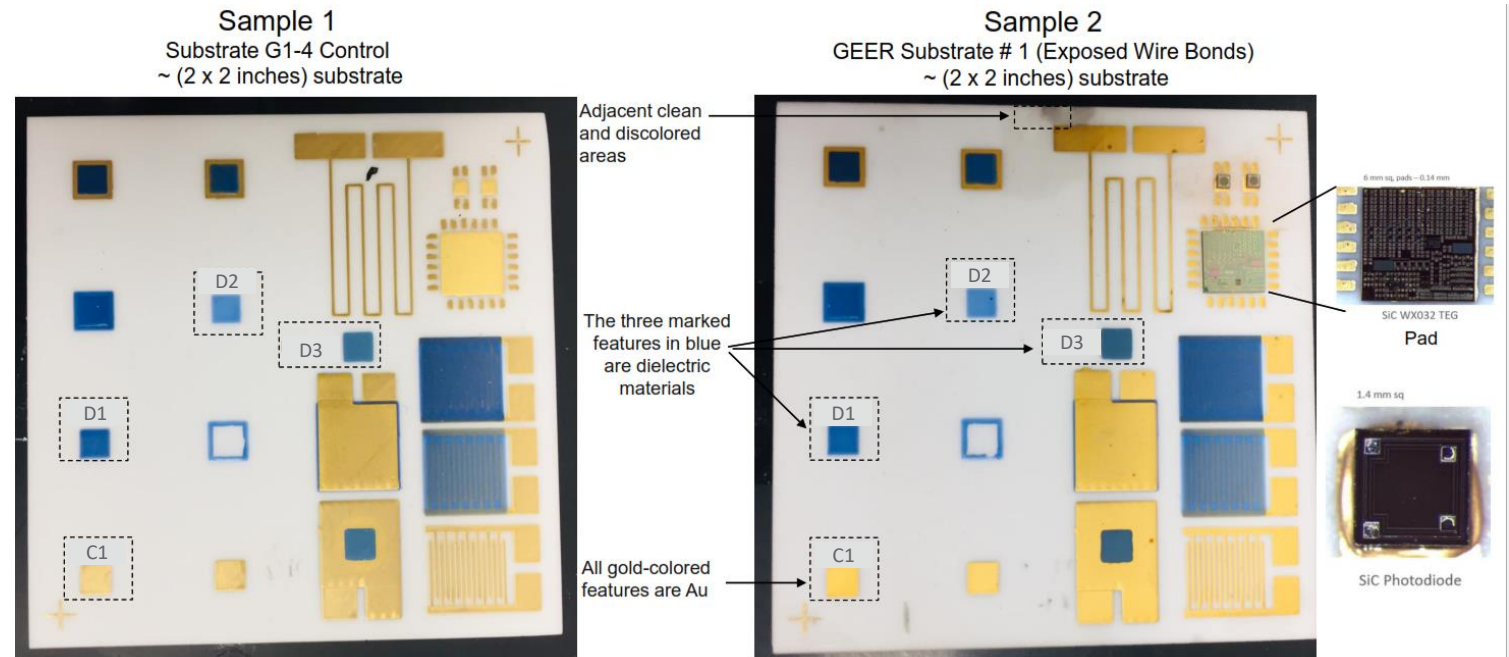
Post GEER Test – Chemical XPS Analysis

After the first GEER testing the surface chemistry of the die pads, conductors and dielectrics were analyzed using a **Physical Electronics (PHI) Genesis XPS Microprobe** to detect chemical reactions during the test. The Phi Genesis can perform XPS (Al K α), HAXPES (Cr K α), and Ar⁺ depth profiling. The instrument stage can accommodate 80 mm x 80 mm. The Phi Genesis was used to characterize the surface (Al K α) and subsurface chemistry (Cr K α , Ar⁺ depth profiling) after GEER testing and on a Control sample not exposed to the GEER test.

The Cr K α x-ray penetration is ~3x deeper than Al K α x-ray. Microprobe size in x and y is <5 microns for Al X-ray source and <14 microns for Cr X-ray source.



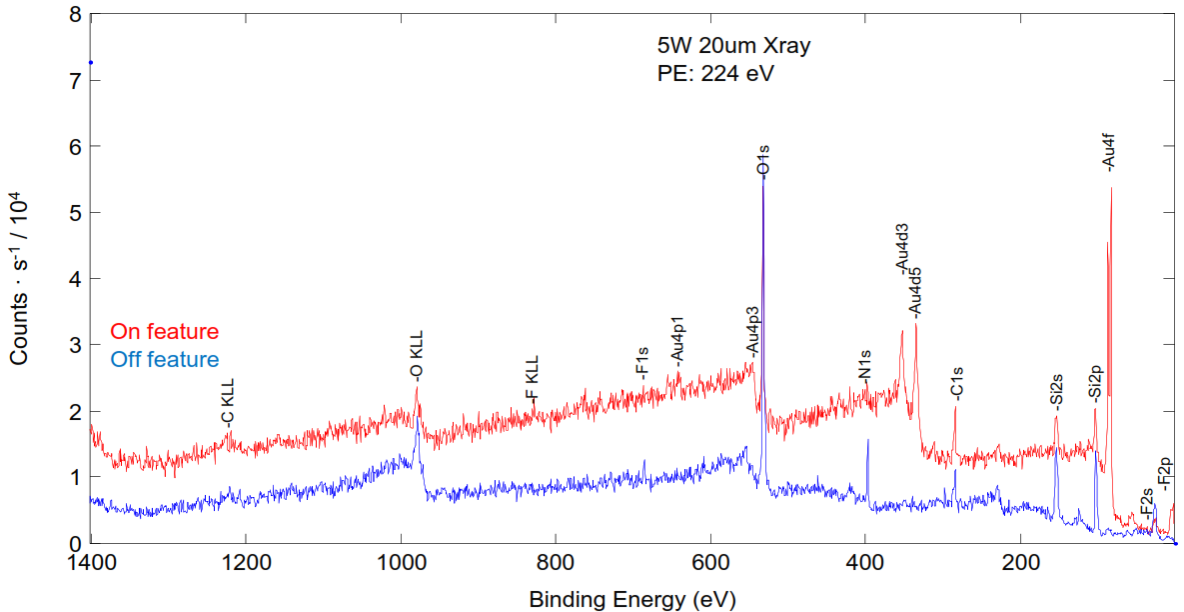
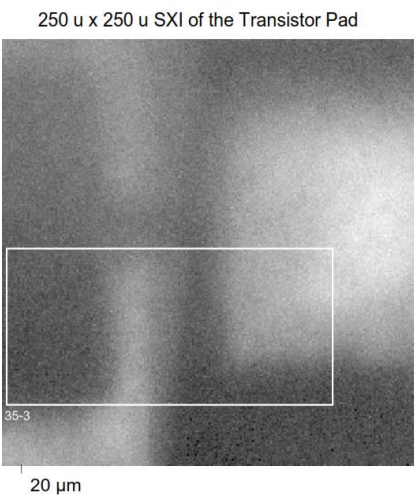
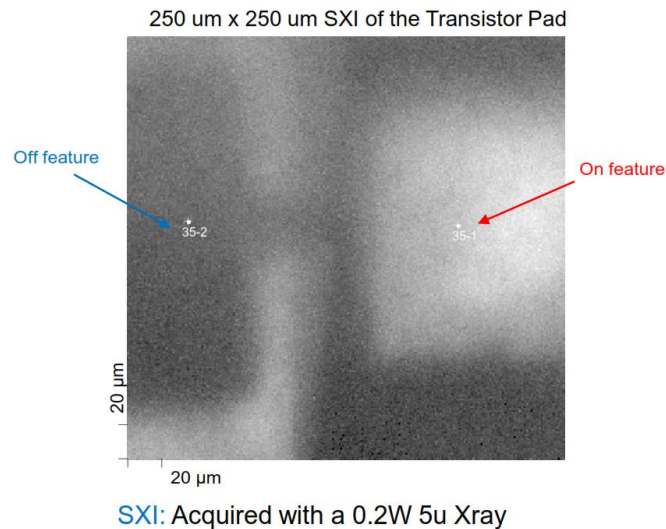
Multi-Technique Scanning XPS Microprobe



GEER test samples: 51 mm x 51 mm x ~1.27-2.0 mm



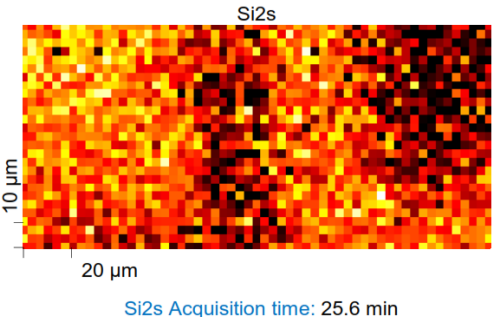
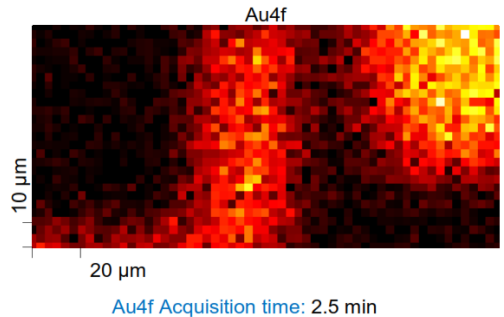
Transistor Pad Al K α Survey after GEER



AC%	C1s	N1s	O1s	F1s	Si2s	Au4f
On feature	26.5	2.3	44.8	0.8	17.6	8.0
Off feature	11.9	11.5	50.2	1.5	24.9	0.0

Au is the primary element on the die pad with some Si, O, N and a small amount of F.

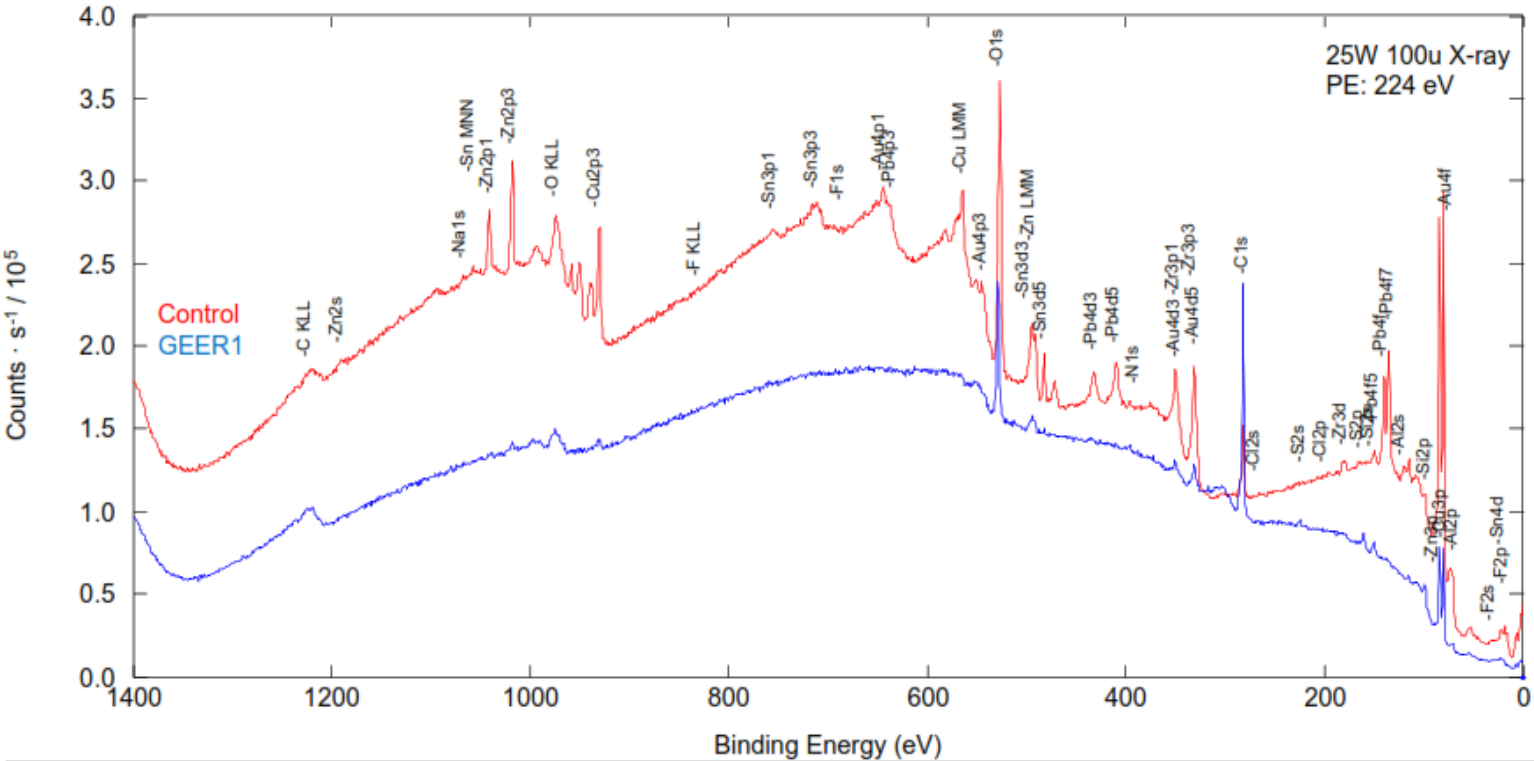
Off the die pad, Si, O, N, and F appear. O, N and Si appear in larger quantities due to the die passivation.



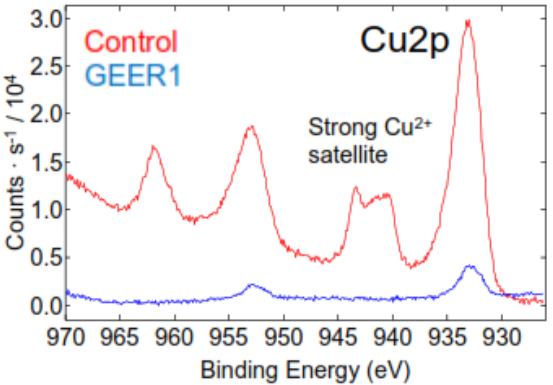
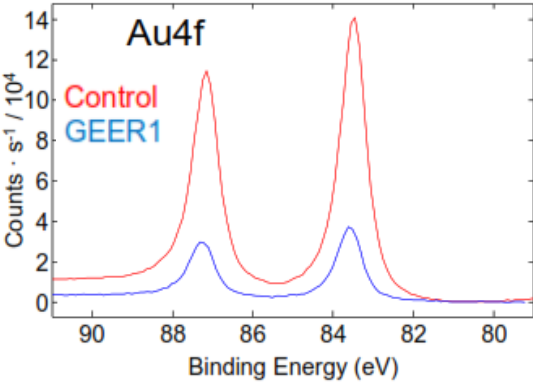
MAP: Acquired with a 1.25W 10um Al K α microprobe 140 eV PE



Post GEER Test: C1 Conductor Al α XPS



AC% from Al K α HR data	C1s	O1s	Al2s	Si2s	Cu2p3	Zn2p3	Zr3d	Sn3d5	Au4f	Pb4f	N1s	F1s	Na1s	S2p	Cl2p
Control	21.2	46.4	6.5	3.8	7.8	4.4	0.6	0.7	5.7	1.7	0.5	0.0	0.3	0.1	0.3
GEER1	70.7	19.0	1.0	3.1	0.6	0.2	0.2	0.6	1.6	0.1	0.9	0.4	0.3	1.1	0.2



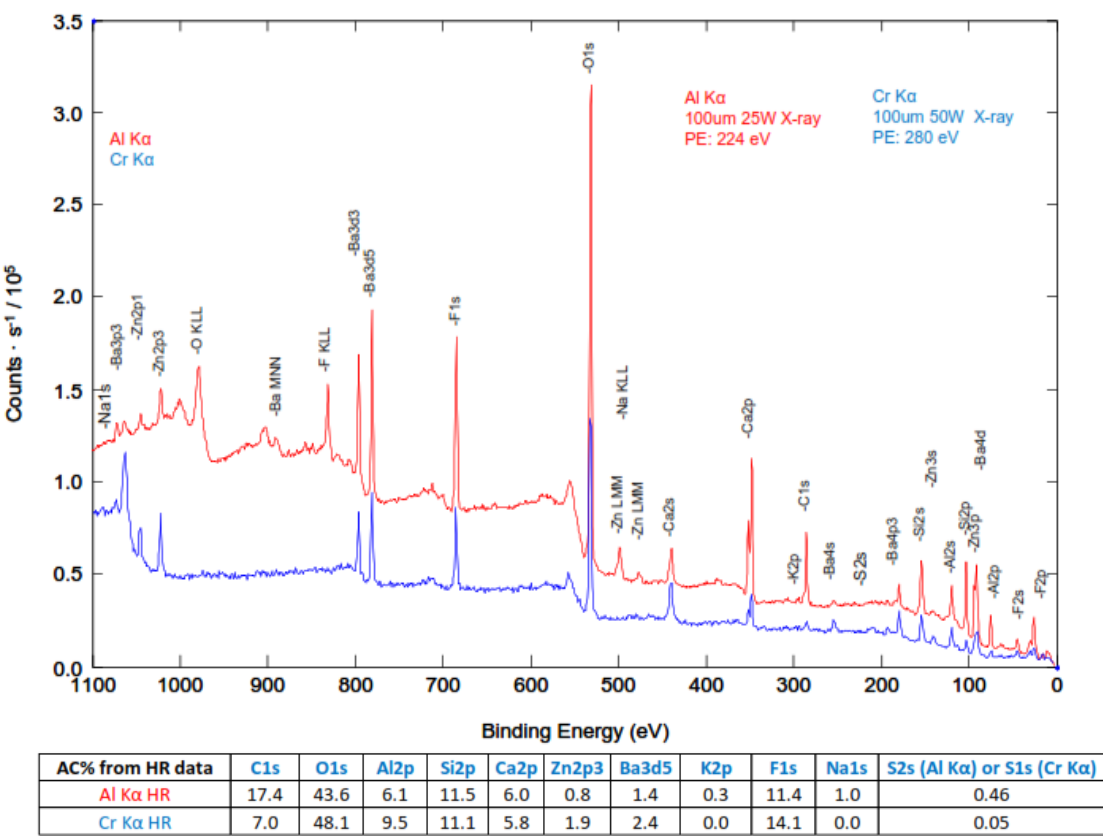
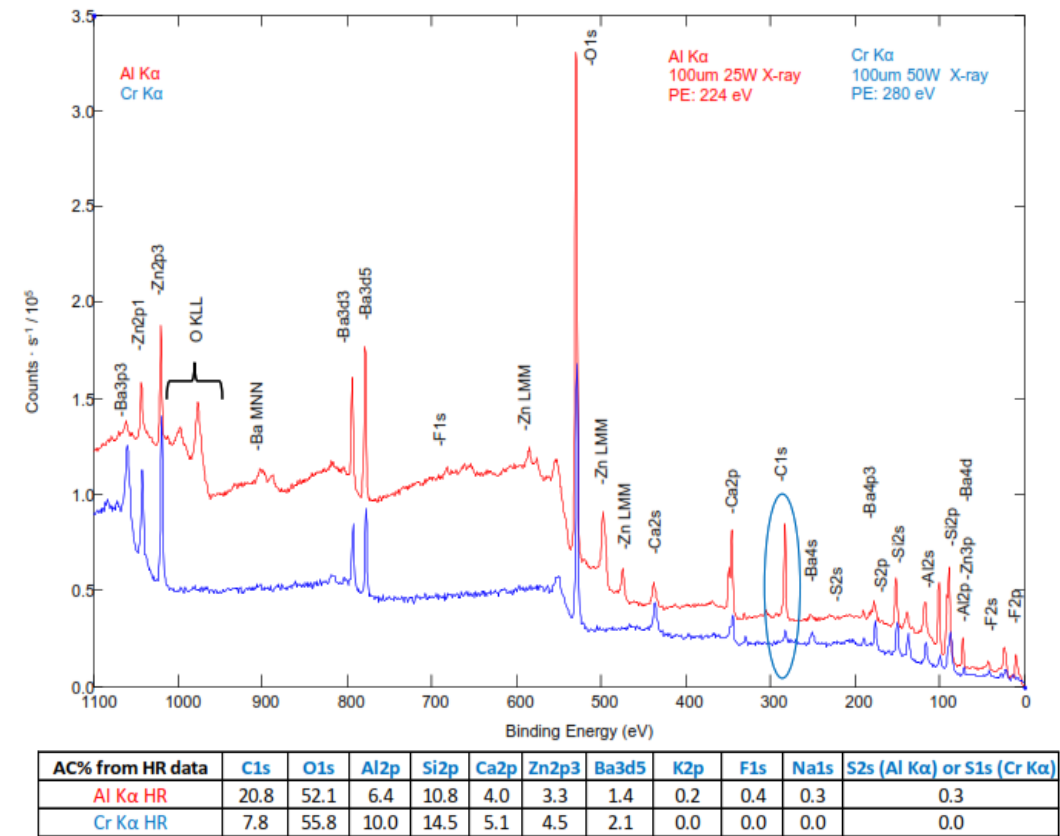
C1 major elements are C, O, Al, Si, Cu, Zn, Sn, Au, and Pb. Zr, N, Na, S, and Cl are in small amounts. GEER sample has higher amount of C, F, and S. Other elements are reduced or had little change. Au binding energy show no reaction. Cu2p shifted from CuO (933.2 eV) to Cu₂O (932.8 eV). Pb4f, Zr3d, Cl2p, N1s, Na1s, Sn3d5/2 remained unchanged. F1s and S2p are only present in the GEER sample. Conductor C1 was unaffected by the GEER test.



Post GEER Test: D1 Dielectric XPS and HAXPES

Dielectric D1 Control

Dielectric D1 GEER

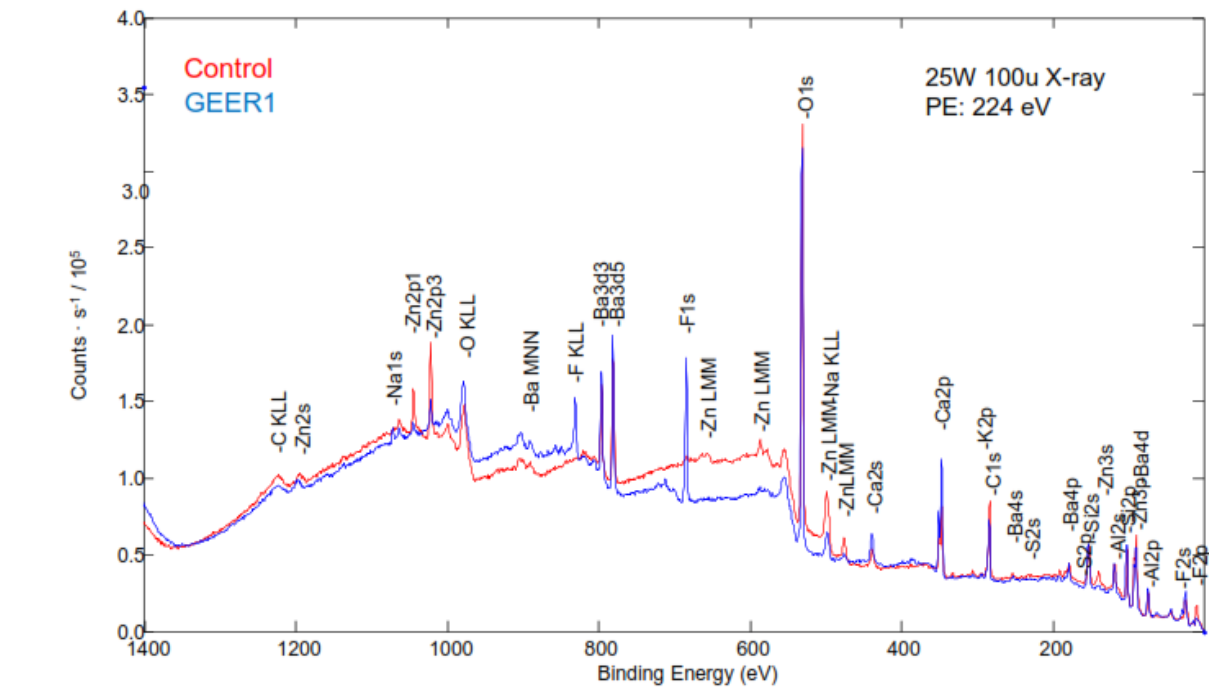


C, O, Al, Si, Ca, Zn, and Ba major elements. K, Na, and S in small amounts on GEER sample surface.
GEER sample has higher amount of F and lower Zn than control sample. Ca and S increased a small amount.

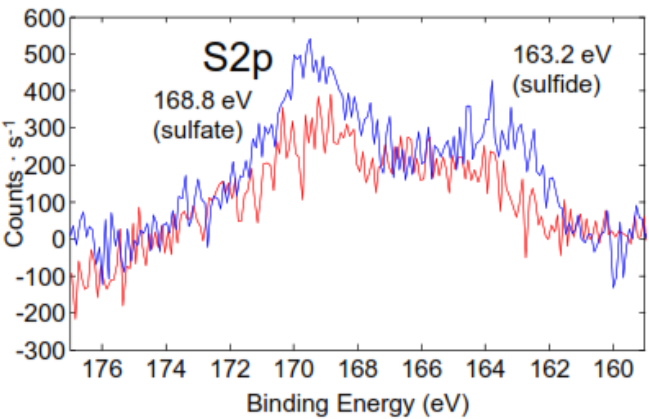
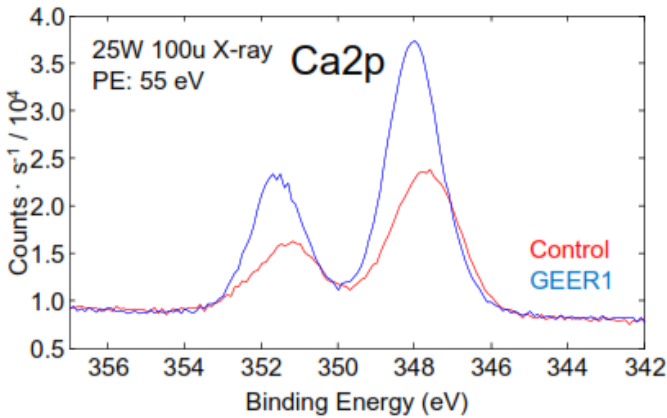


Post GEER Test: D1 Dielectric Al α XPS

Goal: Verify formation of Ca sulfate and sulfide on D1 exposed sample



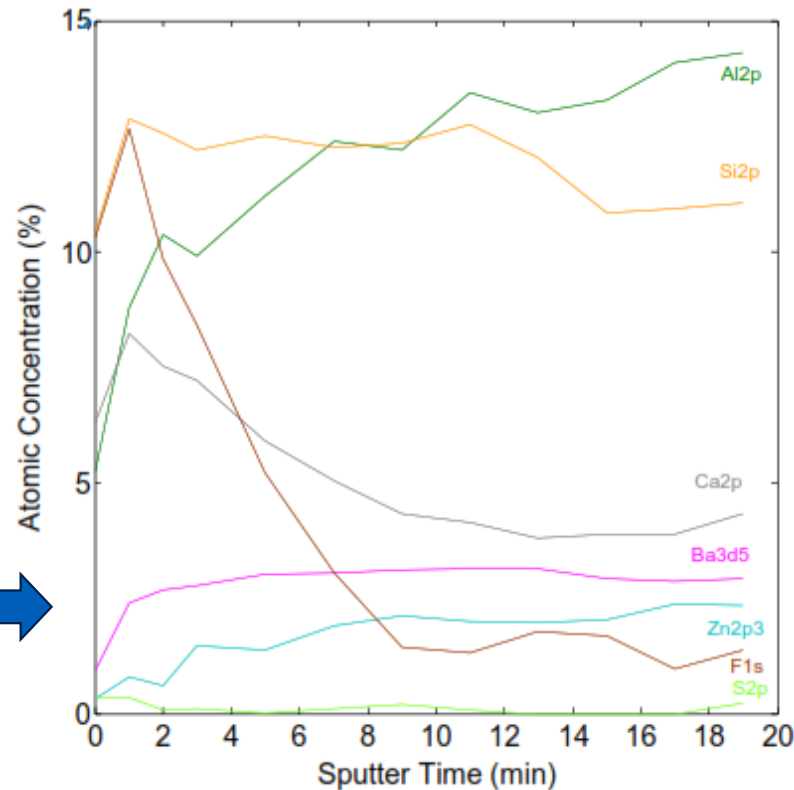
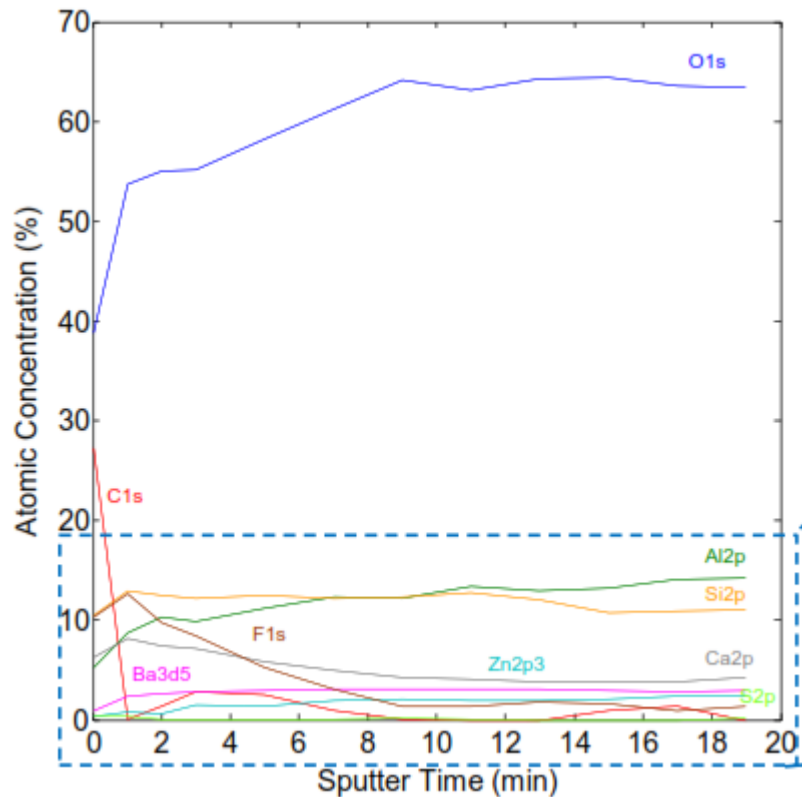
AC% from Al K α HR data	C1s	O1s	Al2p	Si2p	K2p	Ca2p	Zn2p3	Ba3d5	F1s	Na1s	S2s
Control	20.8	52.1	6.4	10.8	0.2	4.0	3.3	1.4	0.4	0.3	0.3
GEER1	17.4	43.6	6.1	11.5	0.3	6.0	0.8	1.4	11.4	1.0	0.5



Sulfur shows two chemical states: sulfate (168 eV) and sulfide (163.1 eV) which increase after GEER. A small amount of Ca may be present as sulfate but very little detected on the surface. Most of the Ca detected is not CaSO₄.



Post GEER Test: D1 Dielectric Ar⁺ Depth Profile



Ar⁺ Sputtering Experimental Details

- Setting: 2 kV Ar⁺ ions with 1 uA of target current rastered over a 3 x 3 mm area
- Total sputter time: 19 min
(Three 1 min sputter steps + Eight 2 min sputter steps)

C1s decreases and disappears with depth indicating it is present only on the surface.

Expected components O1s, Ba3d5, Al2p, Zn2p3, Si2p, and Ca2p increase until reaching a stable composition.

GEER sample surface F is 10x of the control sample and decreases to ~1% after 10 minutes of sputtering.

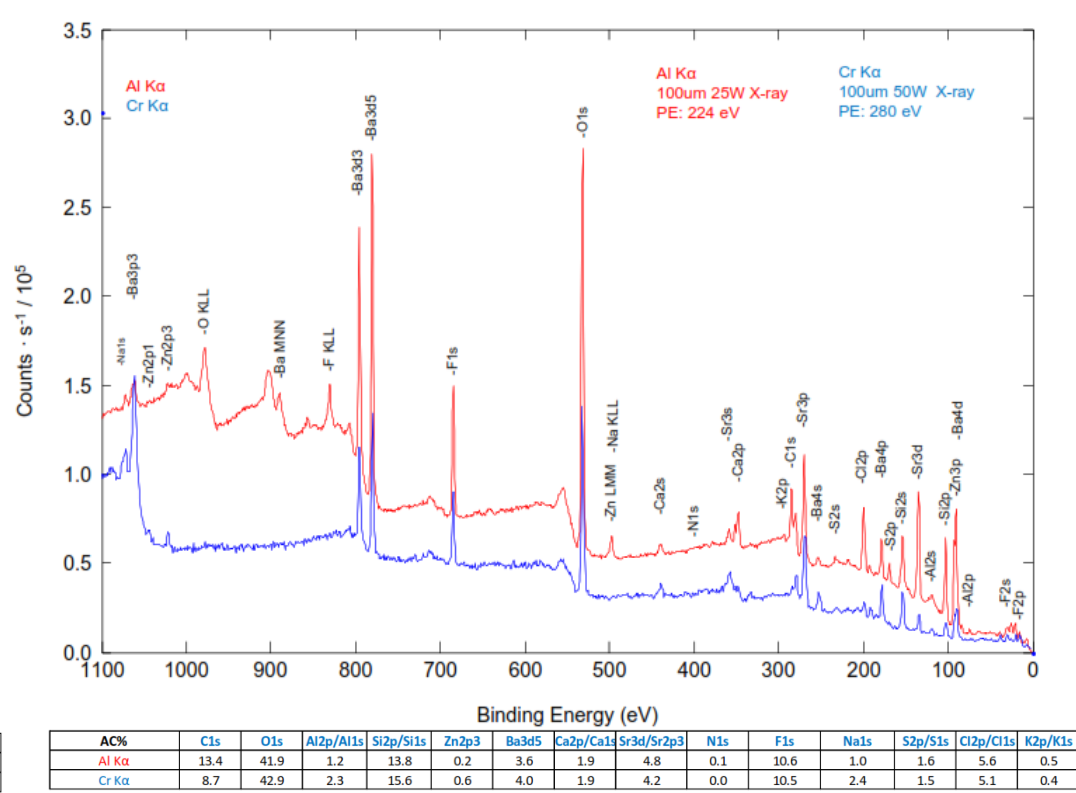
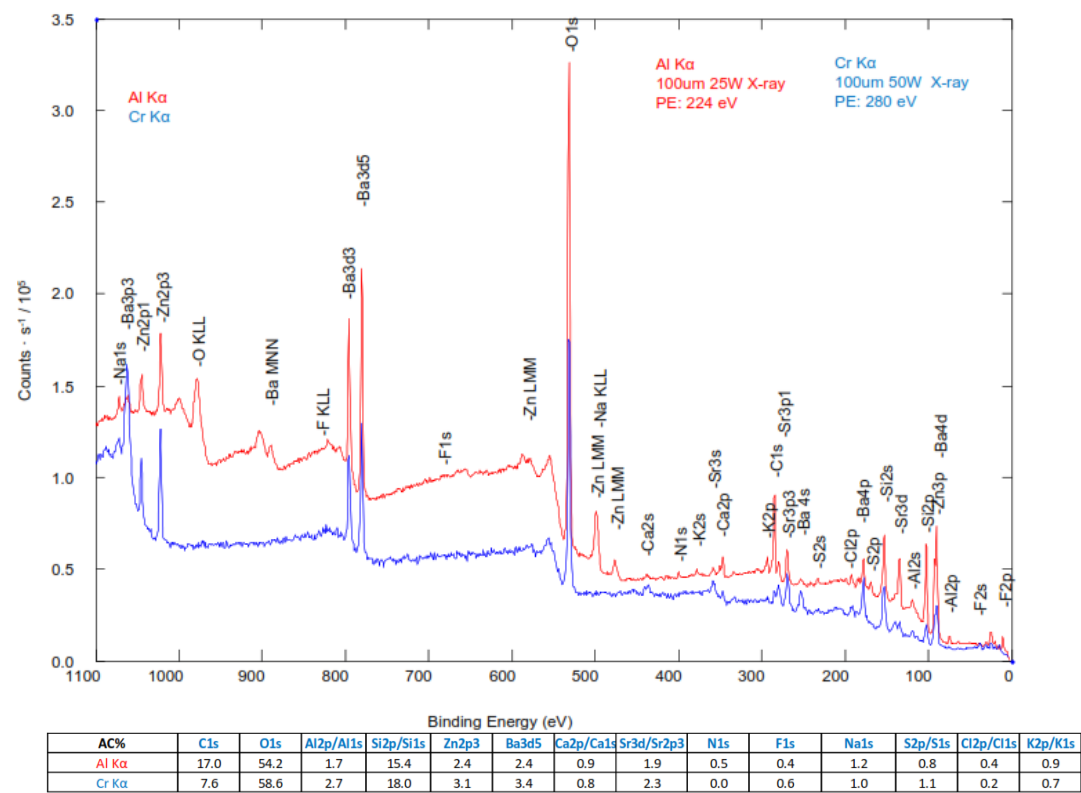
S2p is below the detection limit of XPS and indicates the sulfate may be a thin layer on the surface.



Post GEER Test: D2 Dielectric XPS and HAXPES

Dielectric D2 Control

Dielectric D2 GEER



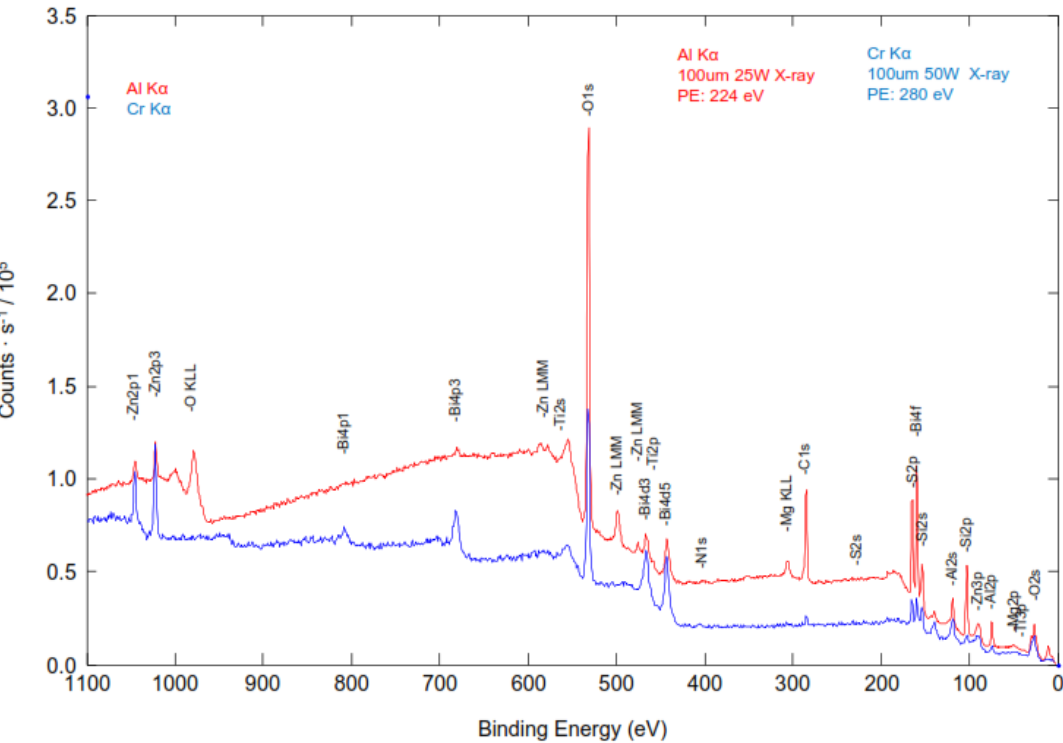
C, O, Al, Si, Ca, Zn, Ba, Sr major elements. N, F, Na, S, Cl and K are present in small amounts in the control. GEER sample has higher amount of F and Cl than the Control. F, S, Cl and K are detected with both sources indicating penetration to the depth of HAXPES depth range. This material targets higher CTE substrates and debonded after firing. It was selected due to its lower Ca level.



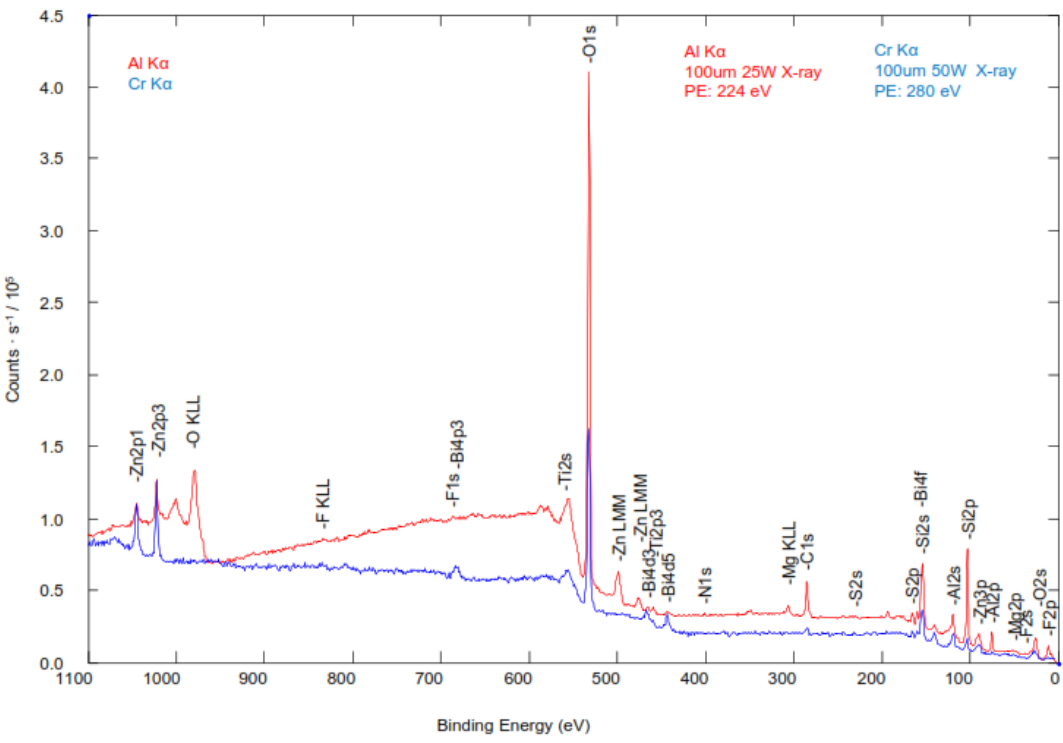
Post GEER Test: D3 Dielectric XPS and HAXPES

Dielectric D3 Control

Dielectric D2 GEER



AC%	C1s	O1s	Al2p/Al1s	Si2p/Si1s	Zn2p3	Bi4f/Bi3d5	N1s	S2s/S1s	Ti2p3/2	Mg2p/Mg1s
Al Ka	25.2	51.7	6.6	12.9	1.4	1.3	0.4	0.2	0.3	0.0
Cr Ka	7.5	59.3	11.2	13.9	3.9	1.6	1.5	0.0	0.0	1.0



AC%	C1s	O1s	Al2p/Al1s	Si2p	Zn2p3	Bi4f/Bi3d5	N1s	F1s	S2s/S1s	Ti2p3/2	Mg2p/Mg1s
Al Ka	13.4	60.7	5.4	18.0	1.3	0.2	0.2	0.4	0.3	0.3	0
Cr Ka	6.6	61.5	8.8	19.1	3.1	0.3	0.4	0	0.2	0	0.4

C, O, Al, Si, Zn, and Bi major elements. S and Ti are present on the surface. Mg is in the subsurface but not on surface. GEER sample has a smaller amount of Bi than the Control. Subsurface N, F, S, Ti and Mg levels are very low (<0.4%) This material was selected since it didn't have Ca content.



Next Steps

- Complete XPS/HAXPES analysis after 2nd GEER test.
- Layout and fabrication of NASA Imager and GE Aerospace photodiode is in process.
- A test circuit will be fabricated and submitted for GEER testing in later 2025.

