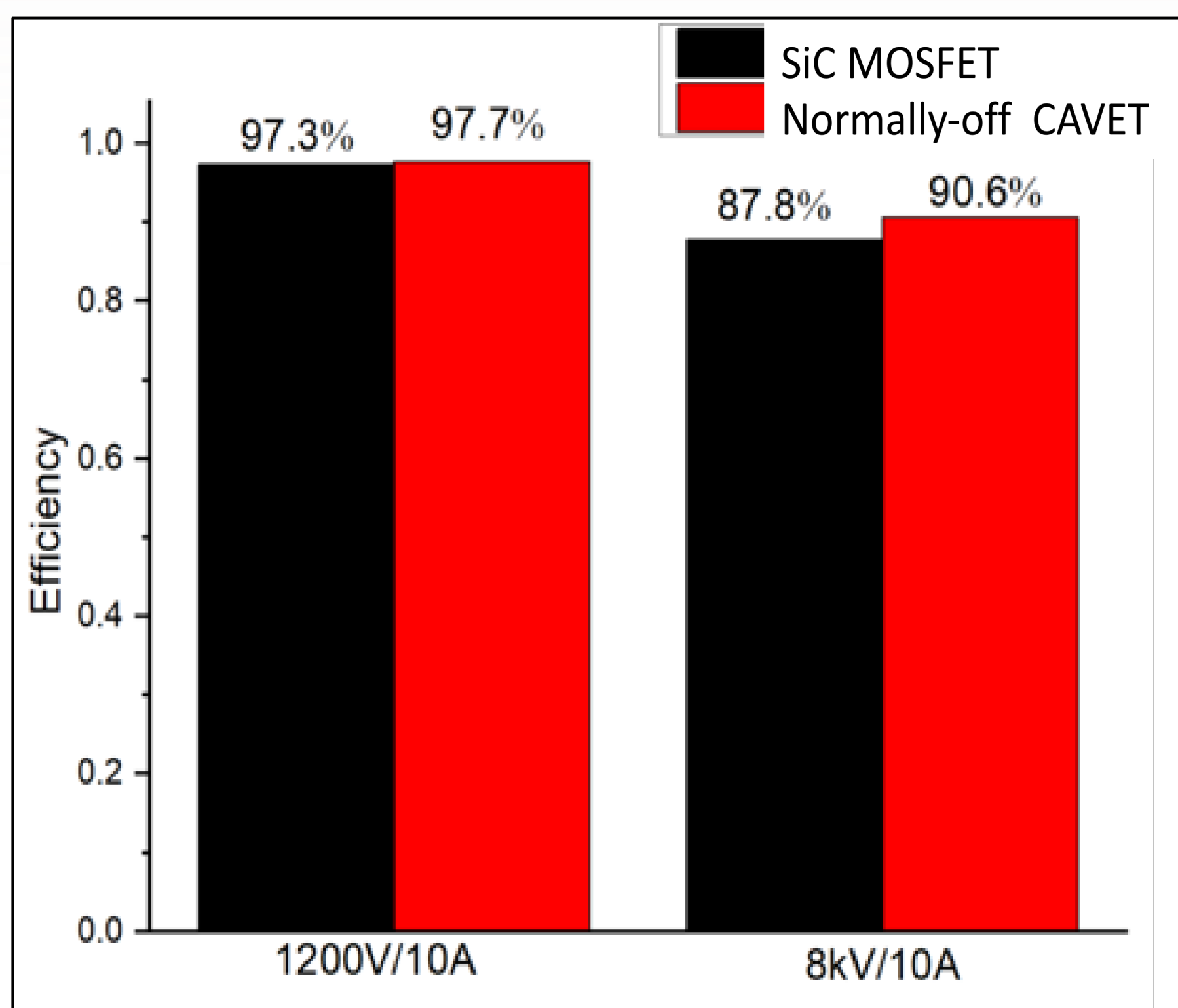


## Foundry Manufacturing of Medium-Voltage Vertical GaN PiN Diodes

### Problem Statement

- Significant needs exist for medium-voltage (~1-100 kV) devices for key energy efficiency applications
  - Transportation electrification (EVs, aviation, rail, marine)
  - Smart grid (solid-state transformers, integration of renewables and storage, HVDC transmission)

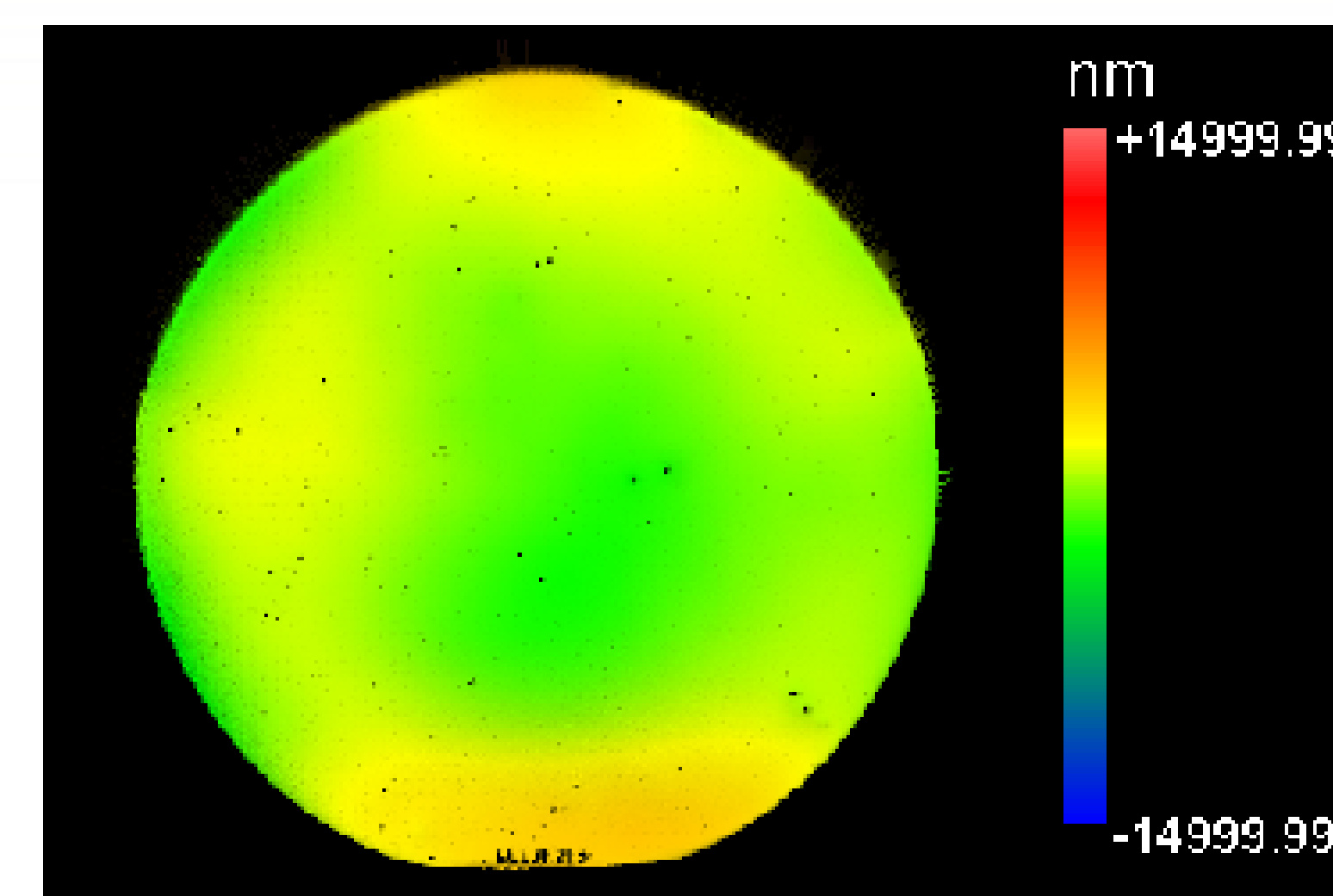


- Vertical GaN may offer efficiency improvements relative to SiC in the medium-voltage regime
- But manufacturing process including yield and reliability evaluation is immature

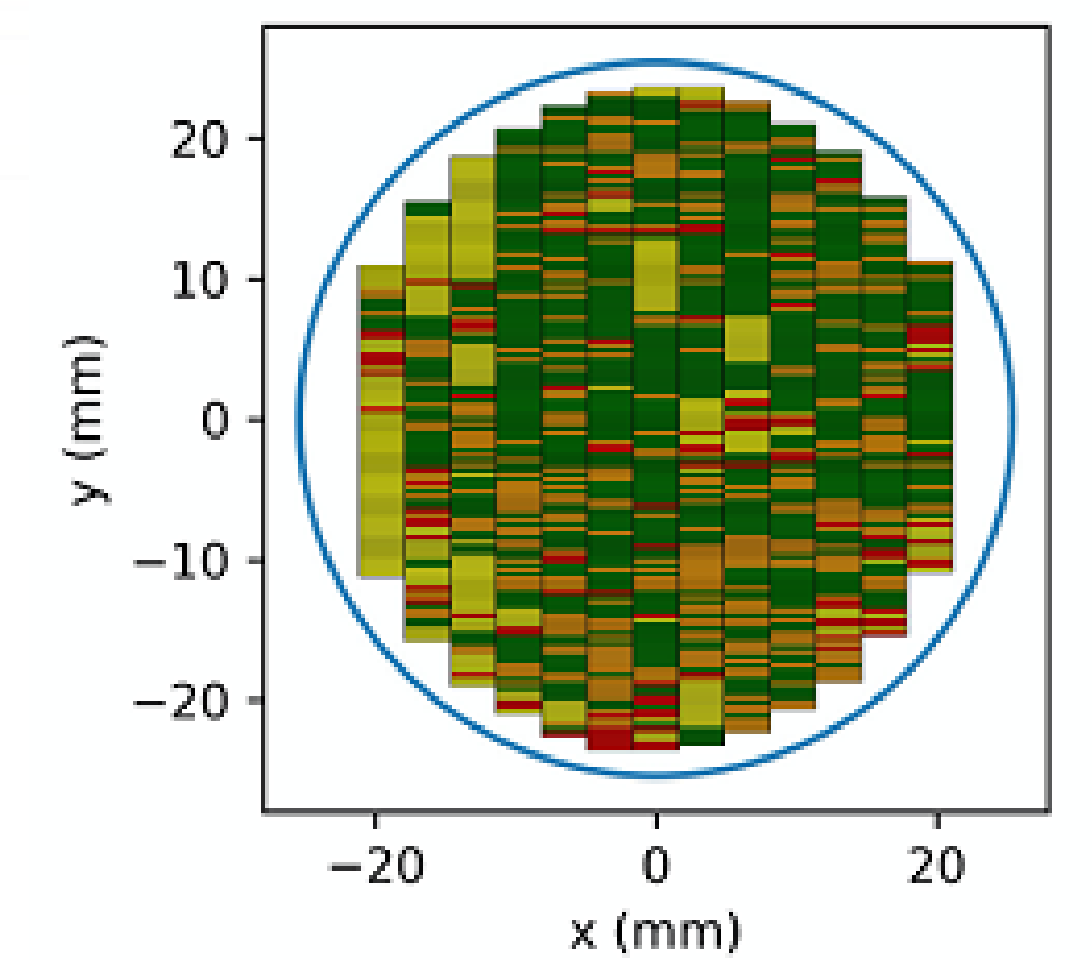
### Incoming Wafer Metrology

Lot	# of wafers	Experiments
1	2	Edge termination
2	4	Vary Anode thickness Alignment to dot-core
3	4	Type I (uniform) substrates
4	4	Vary drift layer thickness
5	6	Vary anode doping and other process variations
6	4	Baseline Process w/ improved epi and high yield wafers
7	3	Baseline Process w/ improved epi and new mask
8	4	New mask, varying implant profiles
9	4	Large-area mask, Back side process demo

- Epitaxial growth done at Sandia by MOCVD and wafers delivered to NRL for characterization and processing
- >35 wafers delivered
- >26,000 devices processed to date

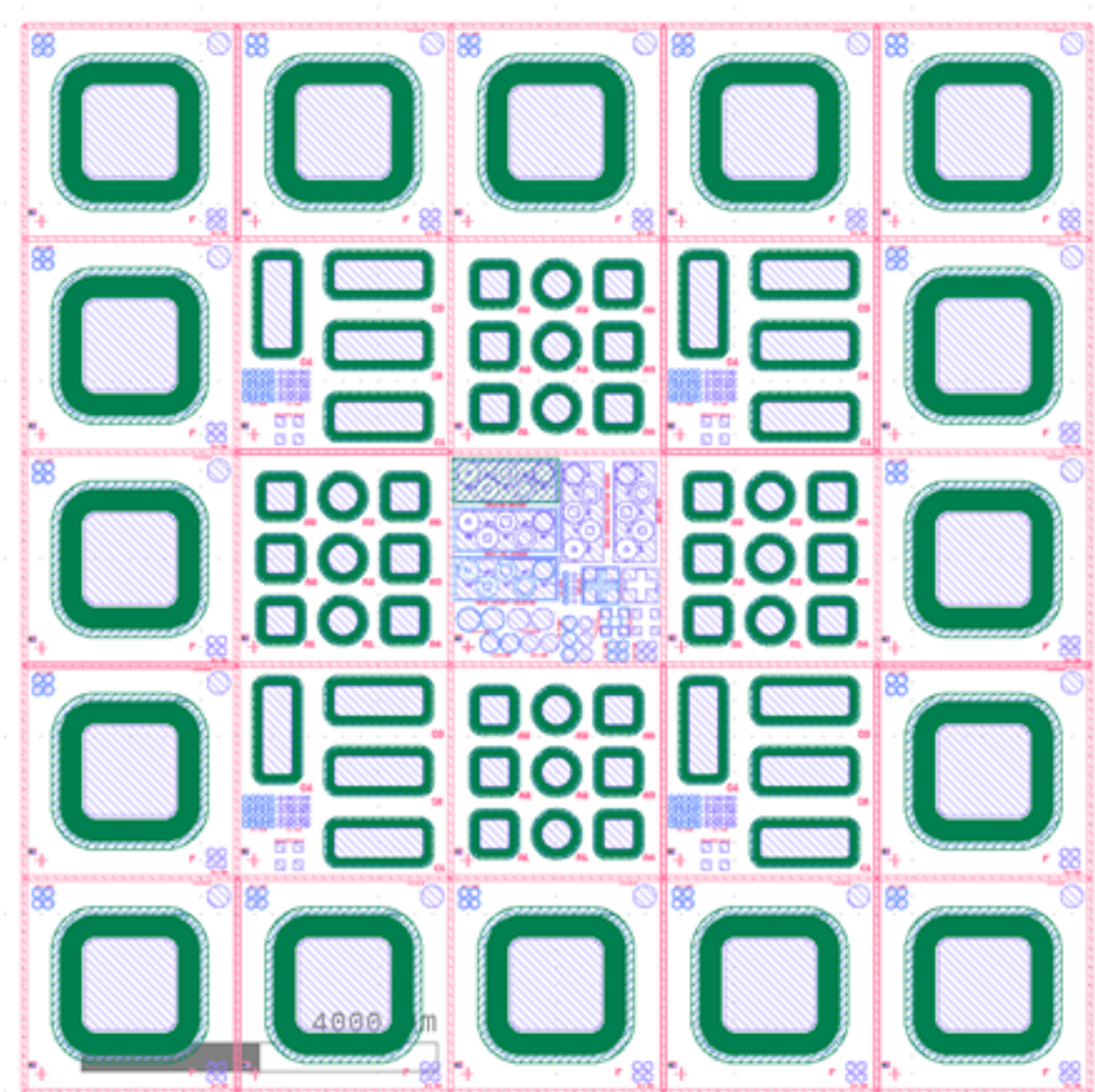


Raw optical profilometry data

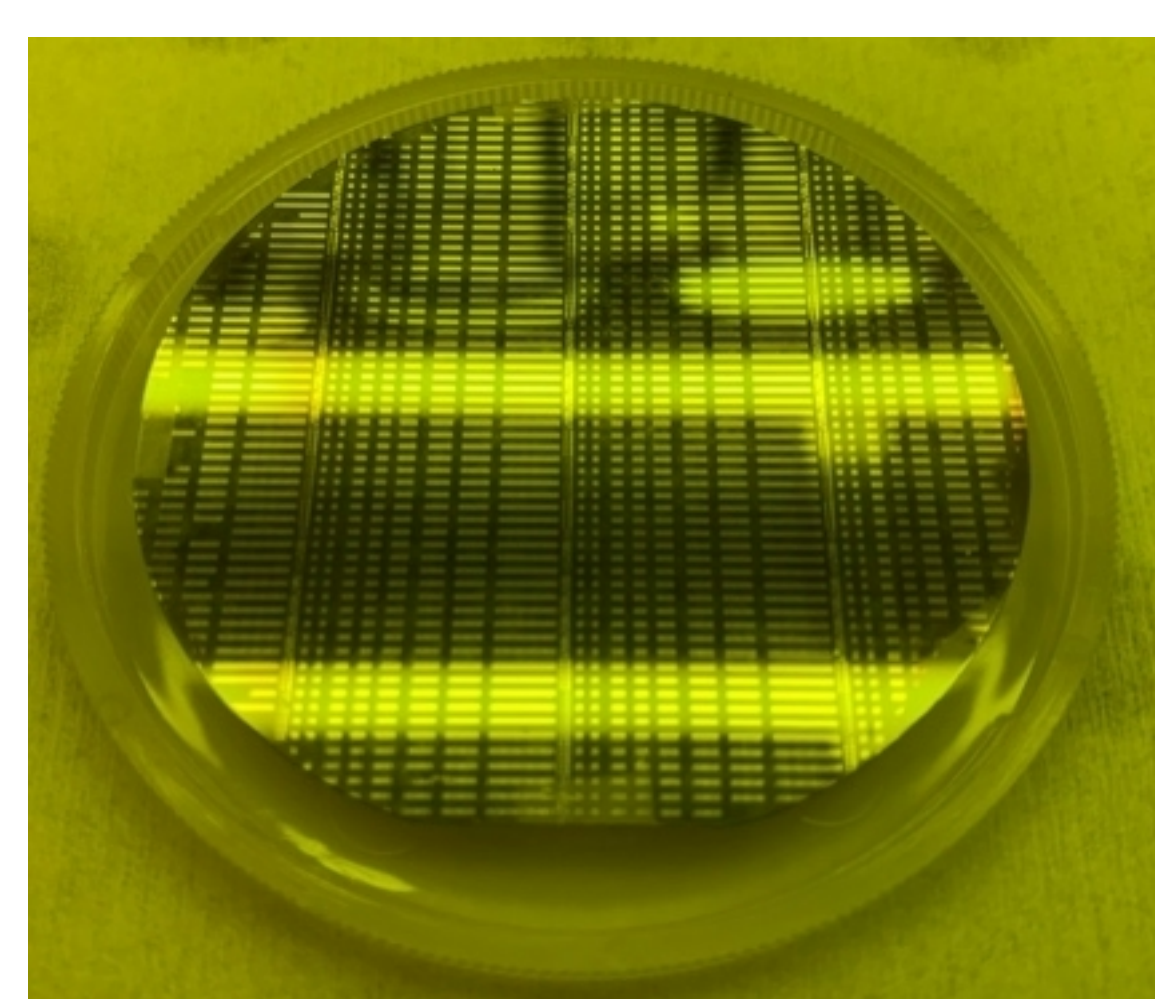


Anticipated 1 mm<sup>2</sup> device yield

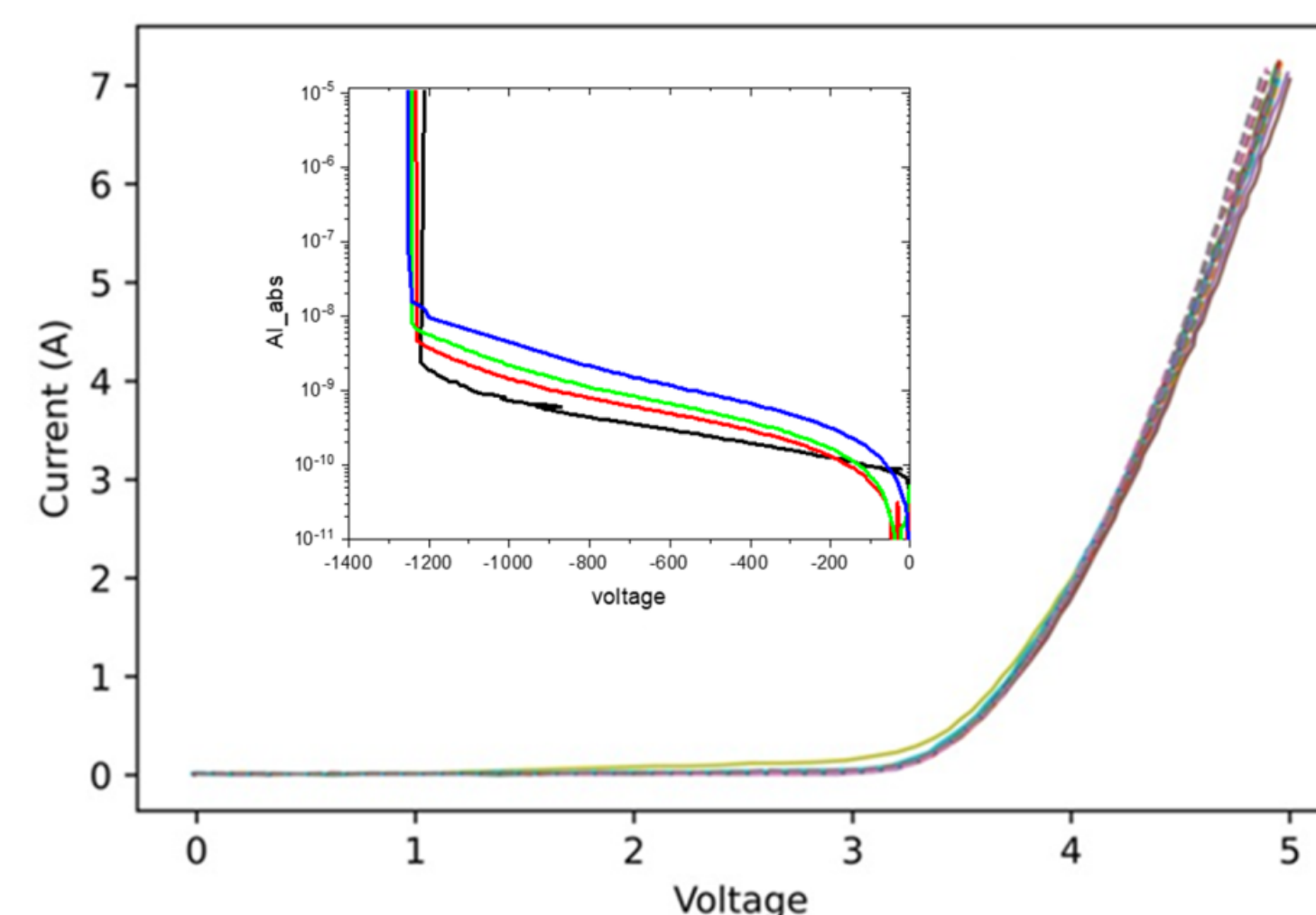
### Foundry mask layout



### Device Processing and Characterization

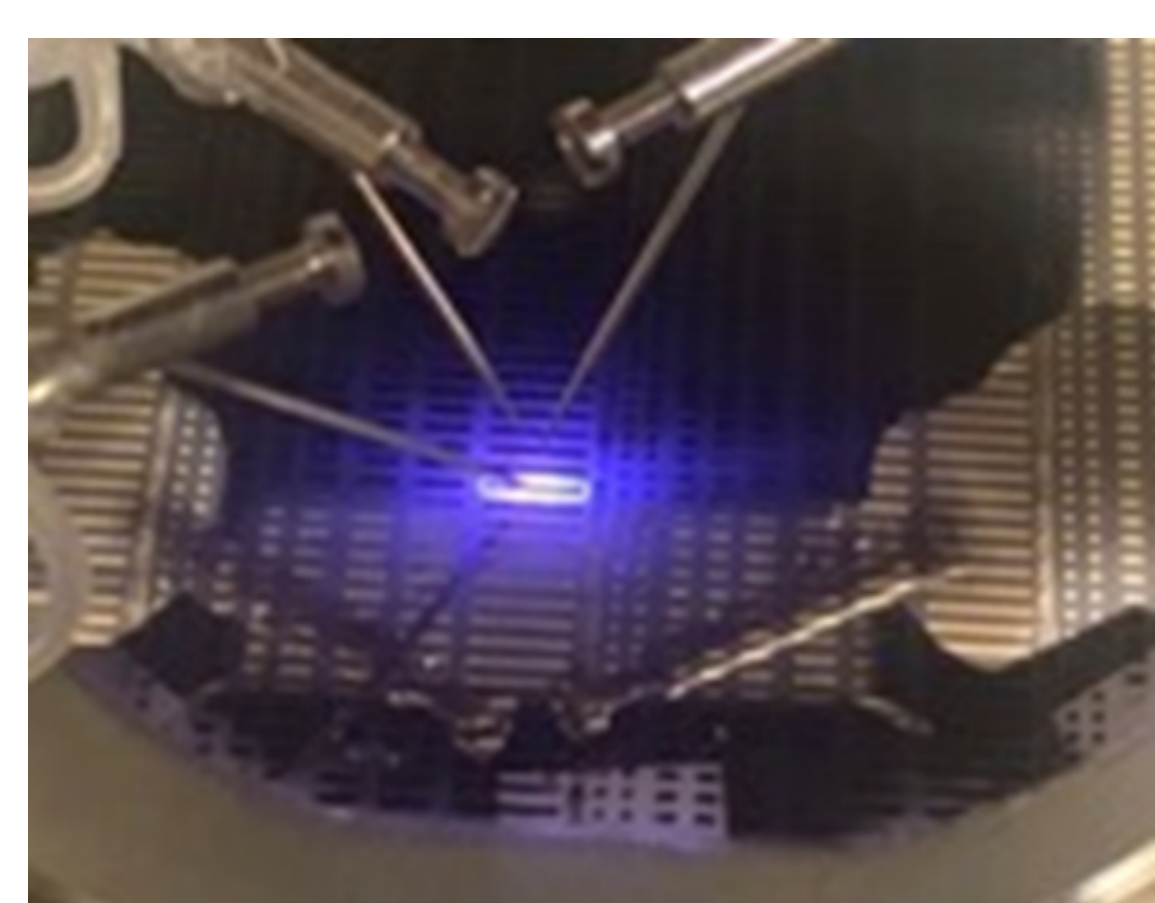
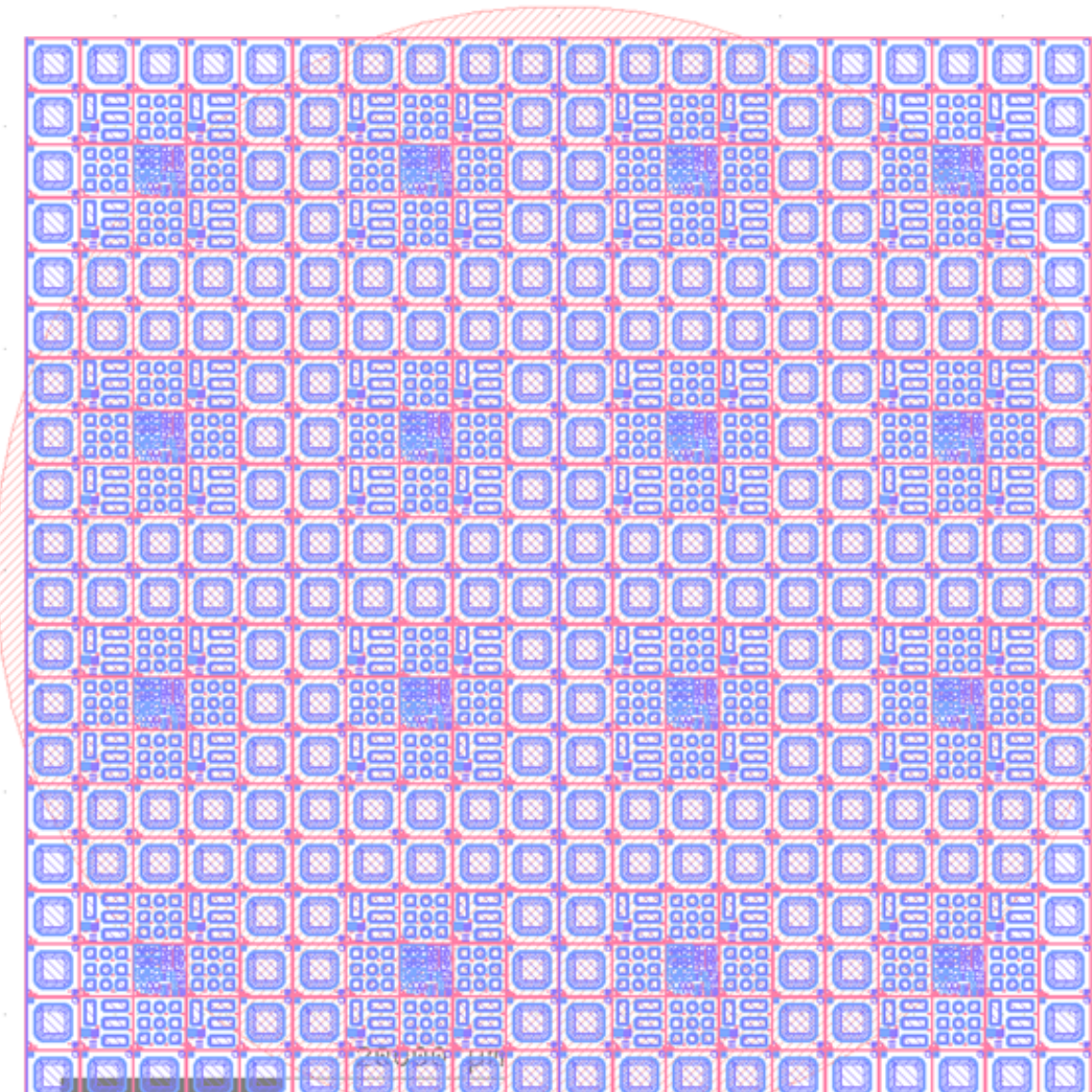
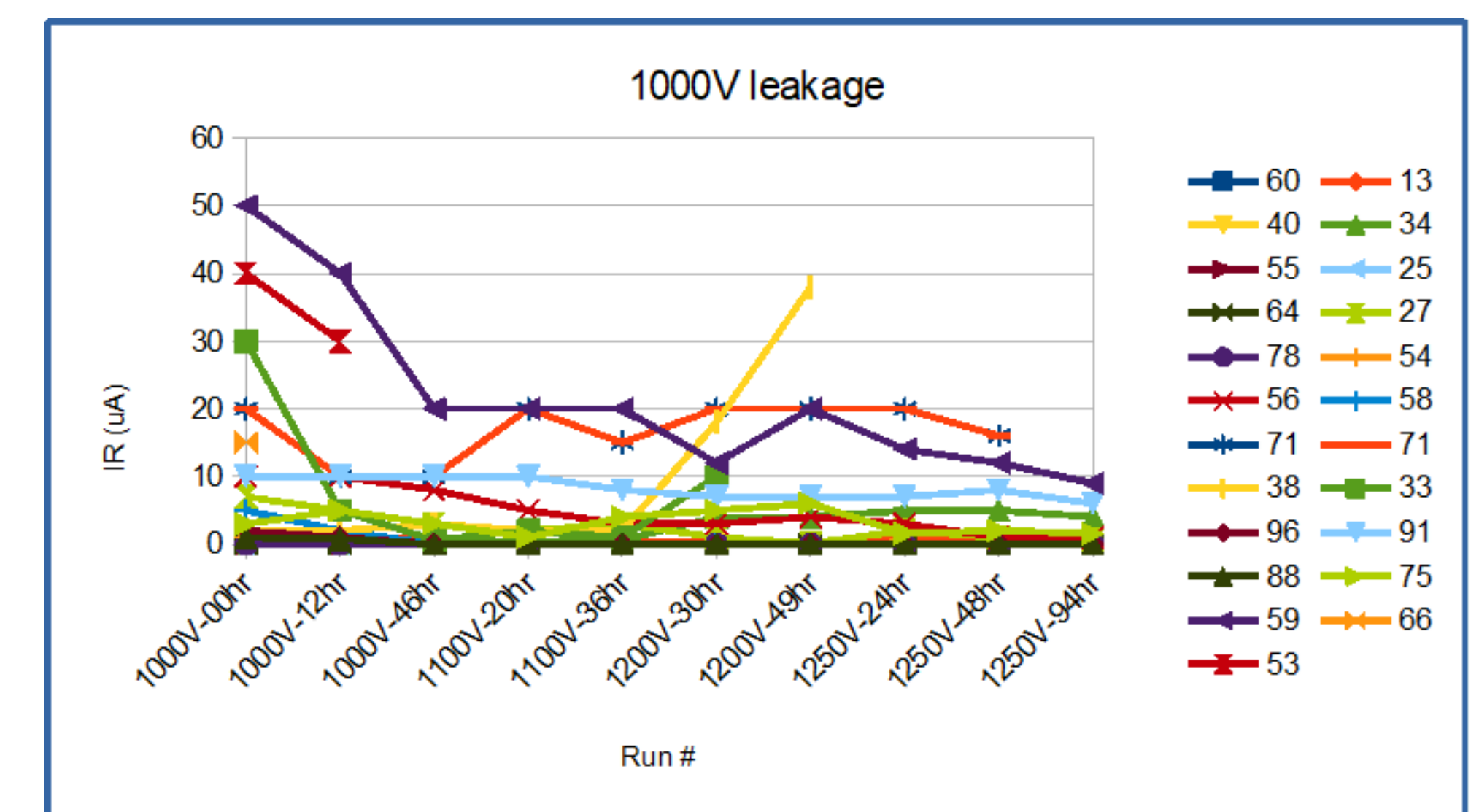


Typical foundry wafer



Forward and reverse IVs

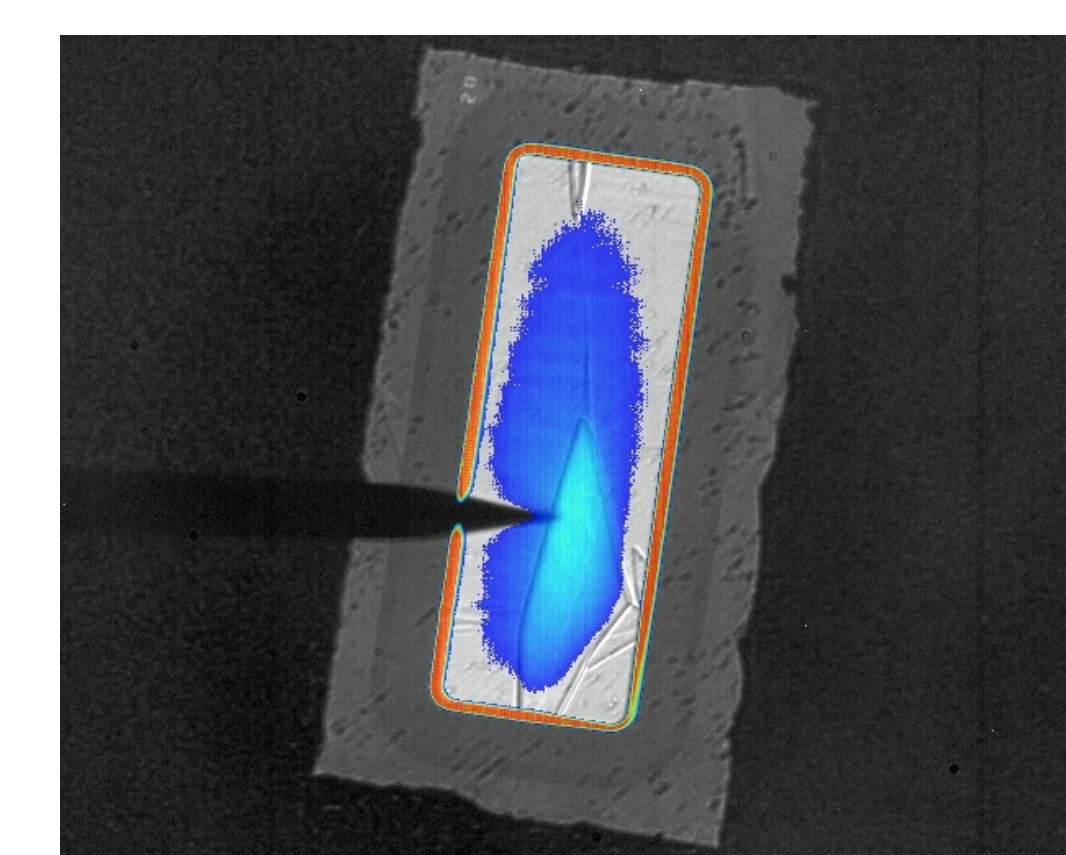
### Reliability testing



Wafer under test

Breakdown (V)	I <sub>c</sub> (A/cm <sup>2</sup> )	R <sub>on</sub> (Ω-cm <sup>2</sup> )	N <sub>d</sub> (cm <sup>-3</sup> )
187	8.54E-03	2.71	2.60E+16
199	8.05E-03	2.53	2.55E+16
437	6.42E-03	2.43	2.54E+16
744	6.28E-05	2.37	2.54E+16
210	6.14E-03	2.36	2.49E+16
729	4.51E-03	2.31	2.58E+16
703	3.34E-05	2.29	2.56E+16
744	2.31E-03	2.21	2.47E+16
759	6.25E-04	2.13	2.57E+16
640	1.99E-05	2.19	2.56E+16
765	5.51E-05	2.18	2.46E+16
764	5.45E-05	2.2	2.43E+16
760	5.75E-05	2.29	2.51E+16
755	4.32E-05	2.27	2.44E+16
760	5.67E-05	2.41	2.42E+16
759	5.91E-05	2.55	2.54E+16
358	4.11E-03	2.63	2.51E+14
760	4.64E-05	2.99	fail

Correlation of measured electrical parameters



### Failure analysis

- Most work to date on 1.2 kV devices
- 3.3 kV device work started