Sandia National Laboratories

Detecting and Minimizing RF Breakdown on Microfabricated Surface Ion Traps

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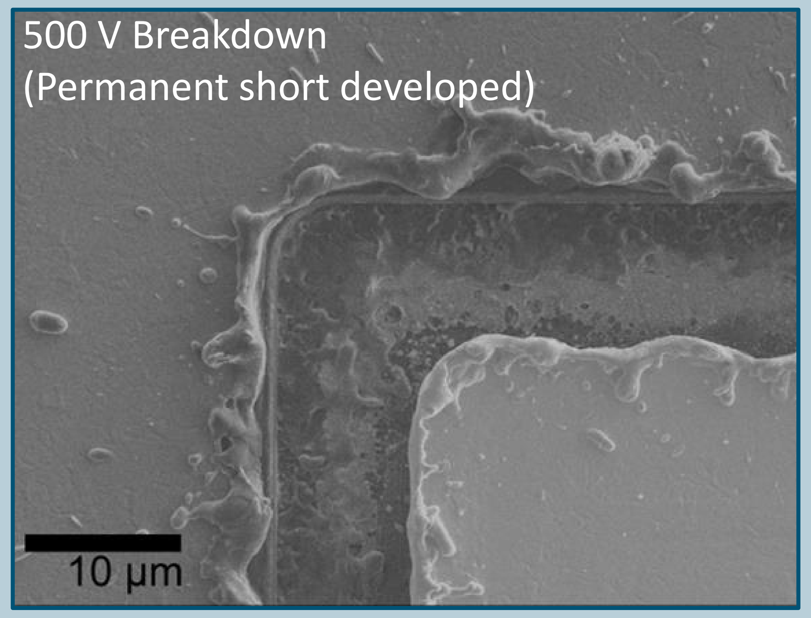
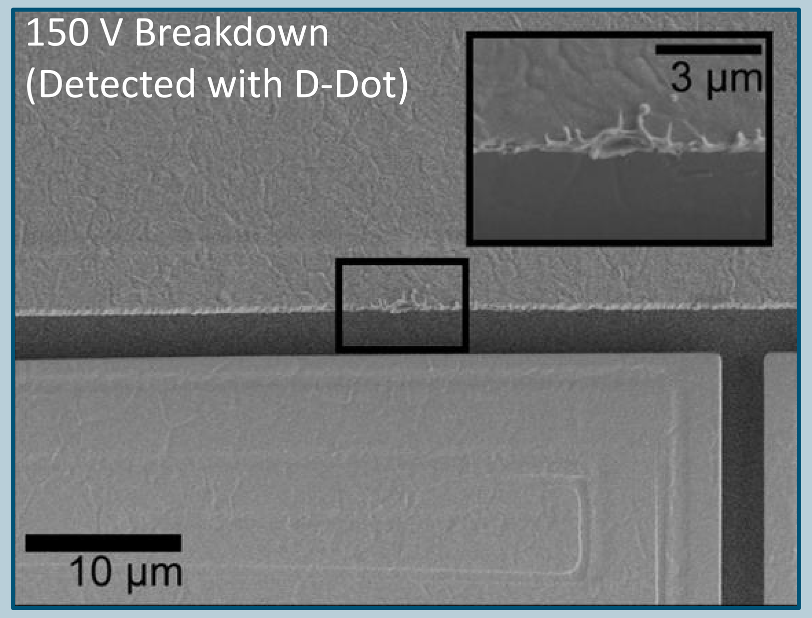
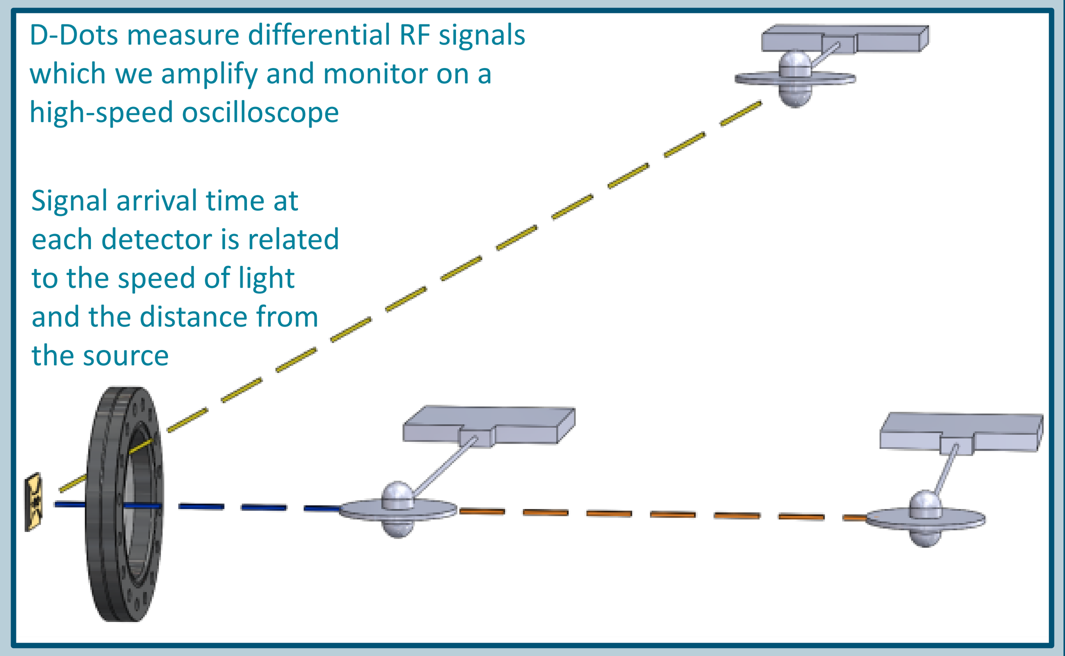
Background

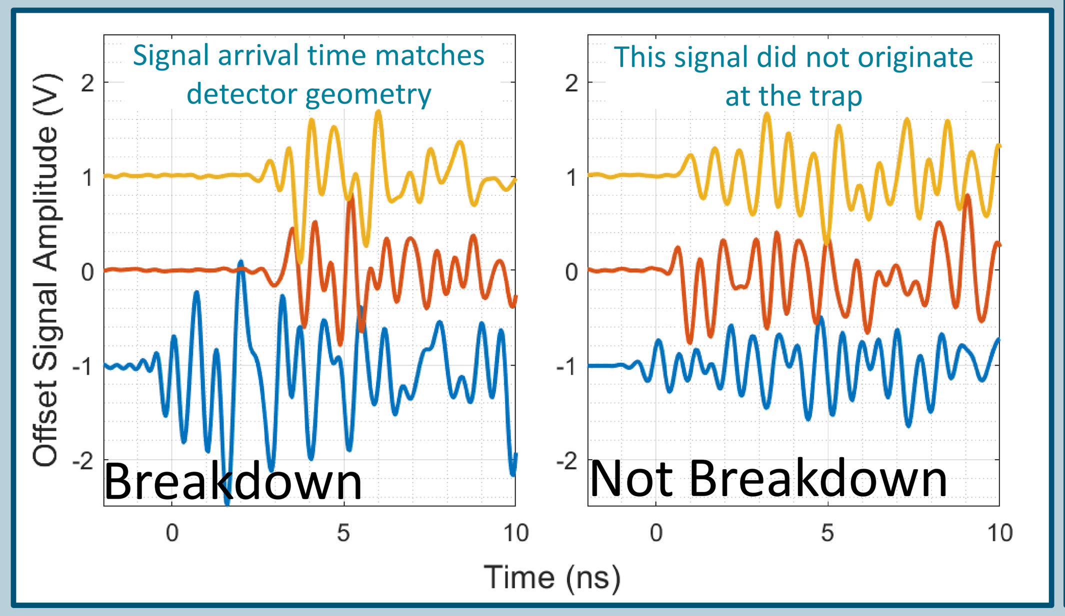
- **Successful ion traps need to sustain high voltage without breakdown**
- Currently impossible to calculate safe operating voltages *a priori*
  - Fabrication uncertainties
  - Unknown physics
- Breakdown causes problems including:
  - No effect
  - Trap instability
  - Total device failure (permanent short)
- Trap failure can take hours or days to occur
  - Often no warning
- We developed two techniques for *in situ* breakdown detection
  - D-Dot detection
  - Back-reflection detection
- Allows detection of small breakdown events
  - Any breakdown can herald catastrophic breakdown
- Techniques employed to characterize breakdown on Sandia devices
- **Best practices developed for safe device operation**

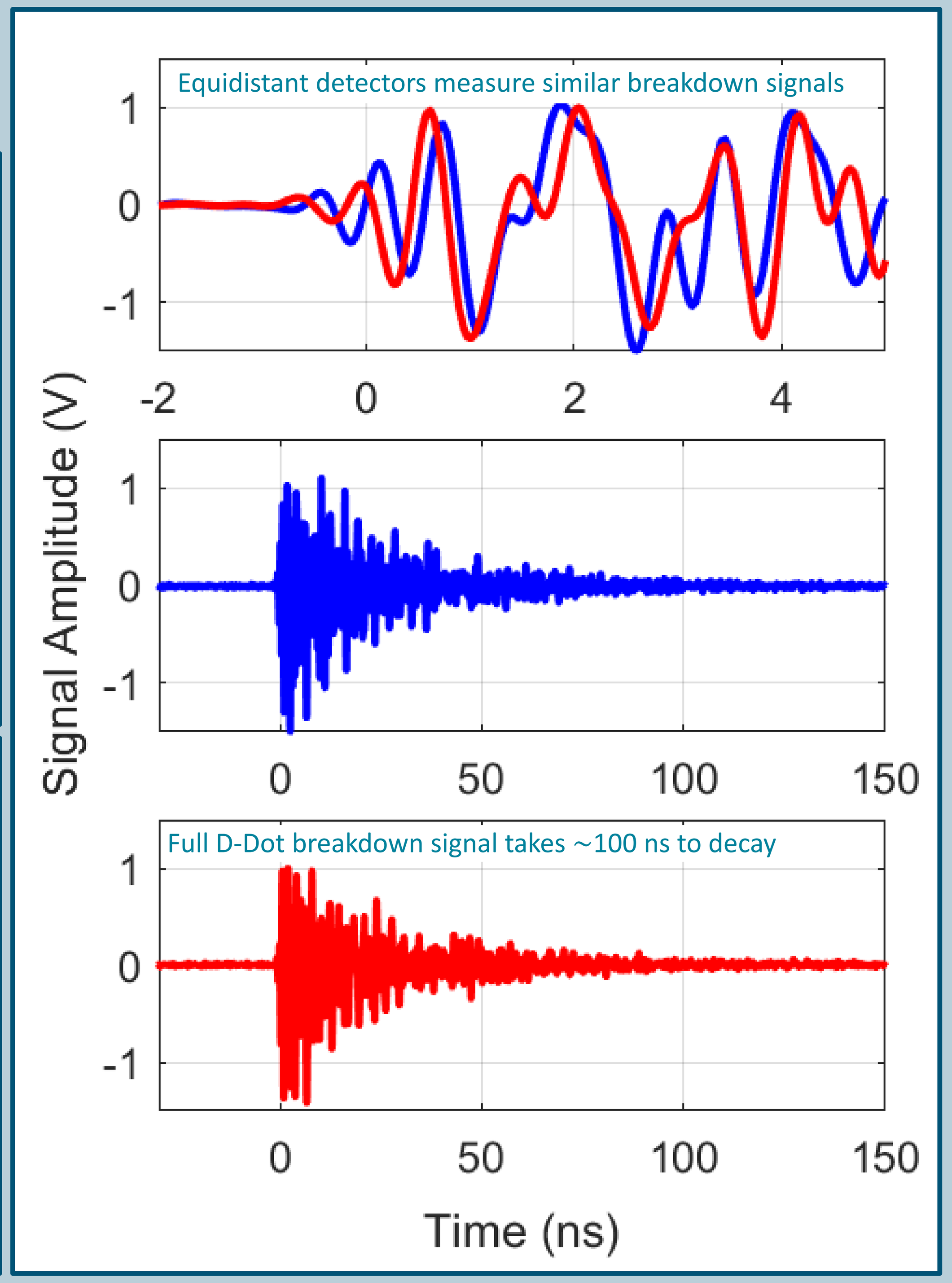




D-Dot Detection



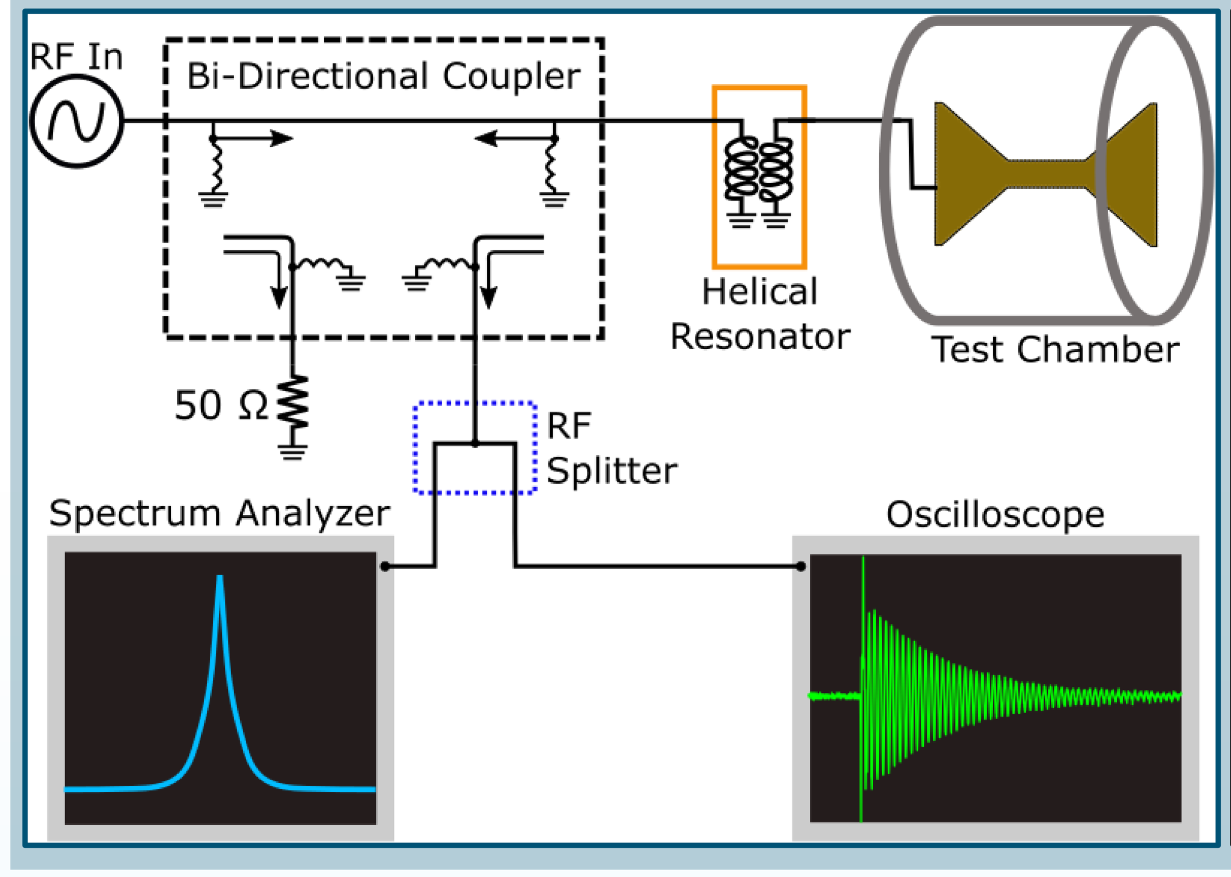


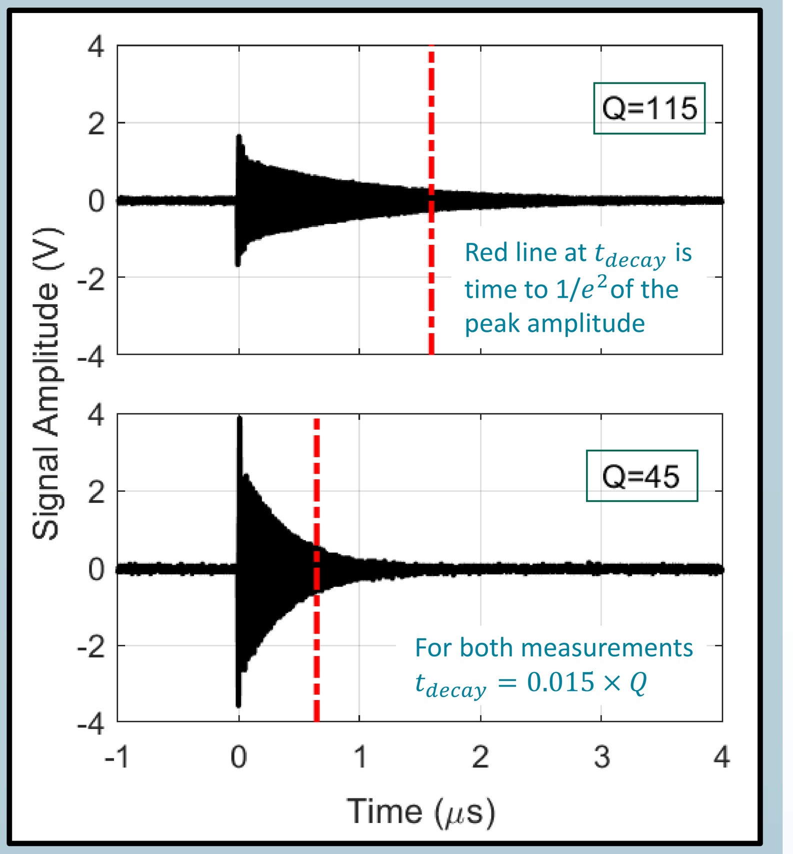


Conclusions and Recommendations

- Breakdown on any device could be catastrophic and should be avoided
- If breakdown does happen, low voltage is better and is often not fatal to the device
- Turn voltage up *slowly* and monitor for breakdown
  - Especially important with new devices
- If a single breakdown event occurs, reduce voltage and wait
  - Voltage increase may be safe later
- Monitoring less critical after several weeks of use

Back Reflection Detection

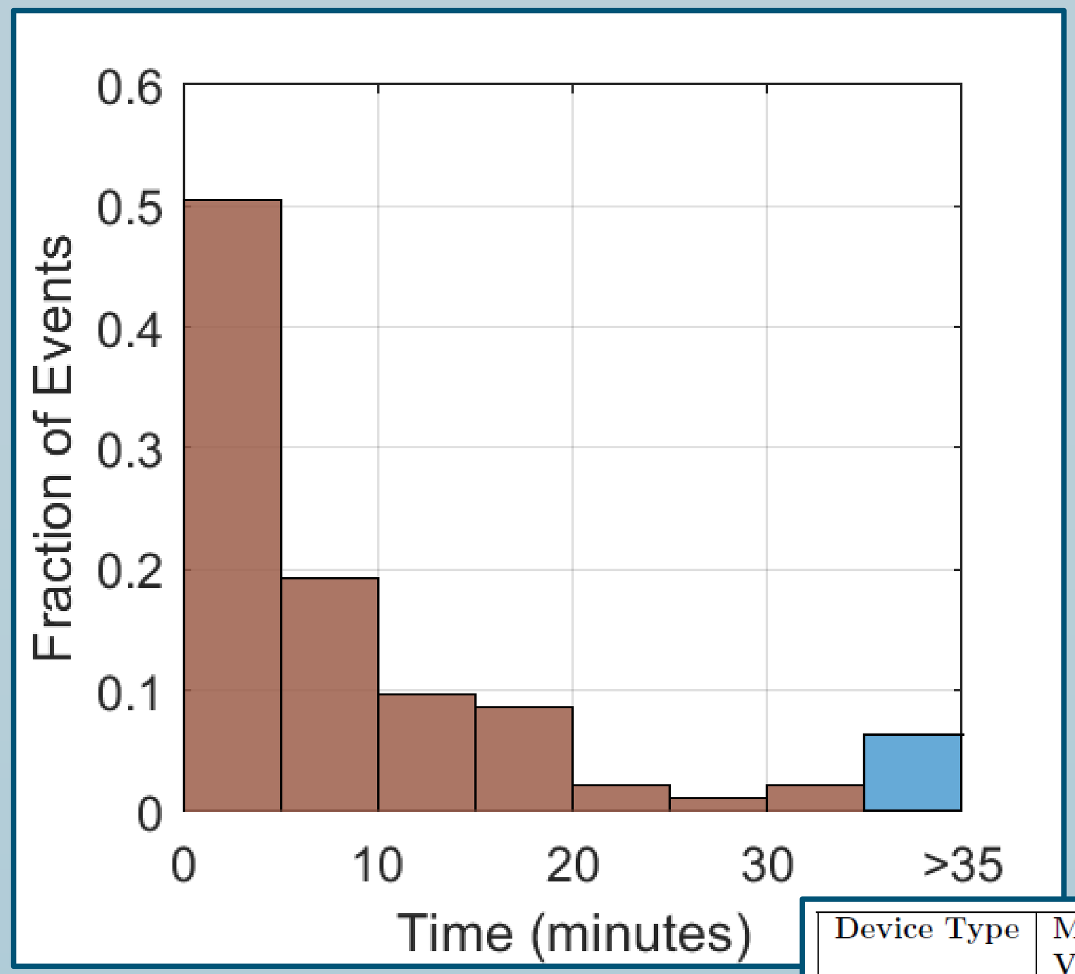




Experiment

- Multiple devices were tested for breakdown, vacuum pressures ranged from low 10^{-7} to high 10^{-10} mbar.
- Voltages were ramped slowly, and held for about 40 minutes at each value (sometimes much longer).
- Ramping continued until rapid, runaway breakdown, or the development of a permanent short.
- If pressure increased above 9×10^{-7} during ramp, voltage was reduced until the vacuum recovered.
- All measurements were done with D-Dots, but the last few device tests also used back-reflection monitoring.

Results

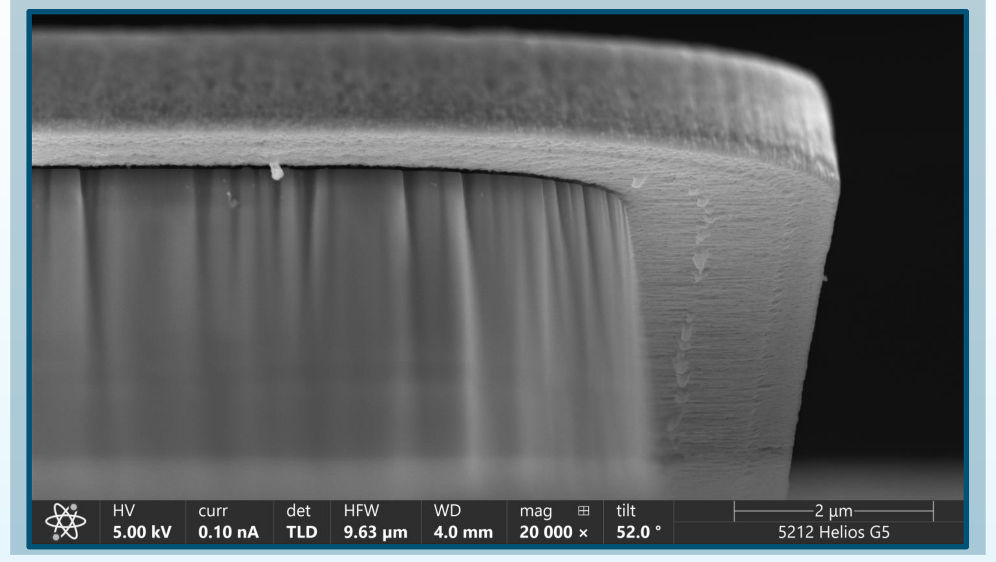


- Large range of initial breakdown voltage
- Variability even for identical devices
- **Most breakdown in first 20 minutes**
- Runaway (rapid, repeating) breakdown usually led quickly to permanent short
- **Higher voltage breakdown = more damage**
- Some devices had only a single catastrophic breakdown
- Often low voltage breakdown was isolated and non-fatal
- Breakdown didn't depend on chamber pressure
- Local pressure at the device probably matters

Device Type	Metal-Gnd Vert (μm)	Metal-Gnd Horz (μm)	Min/Max Initial BD (V)	Min/Max Short (V)
Phx/Prgn 1	2	5	150/190	200/290
Phx/Prgn 2.0	4.7	5	220/190	345/400
Phx/Prgn 2.1	4.7	5	300/300	n/a
Phx/Prgn 2.7	7	5	190/230	n/a
HOA	10	5	200/333	*500*
Tic-Toc	1	3	n/a	*160*
Triangle	2	1.4	175/250	250/275

Future Plans

- Future devices will be monitored for breakdown
- Breakdown experiments with various dedicated test structures are in development
- Fabrication and post processing procedures are being developed to mitigate the formation of asperities (see below)
  - Probable that most breakdown events occur at or near such asperities



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