MICRO-X

CARBON NANOTUBE ELECTRON EMITTER

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BACKGROUND

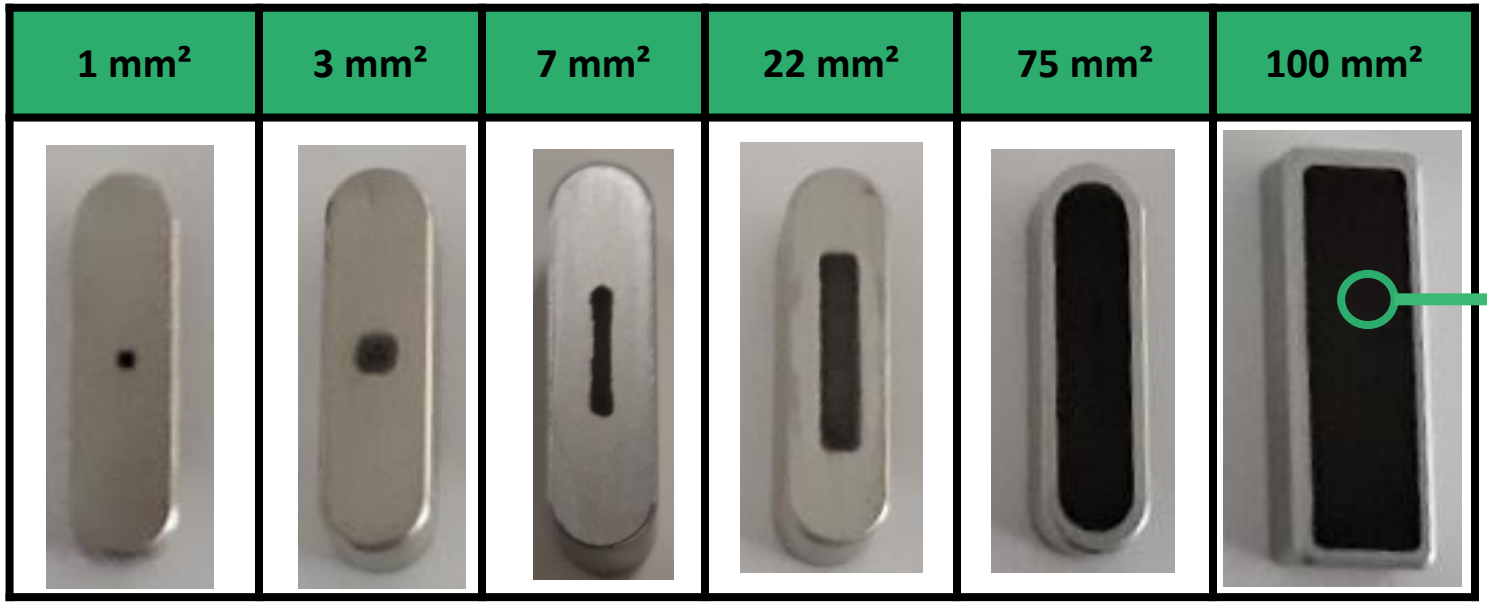
CNT Emitter

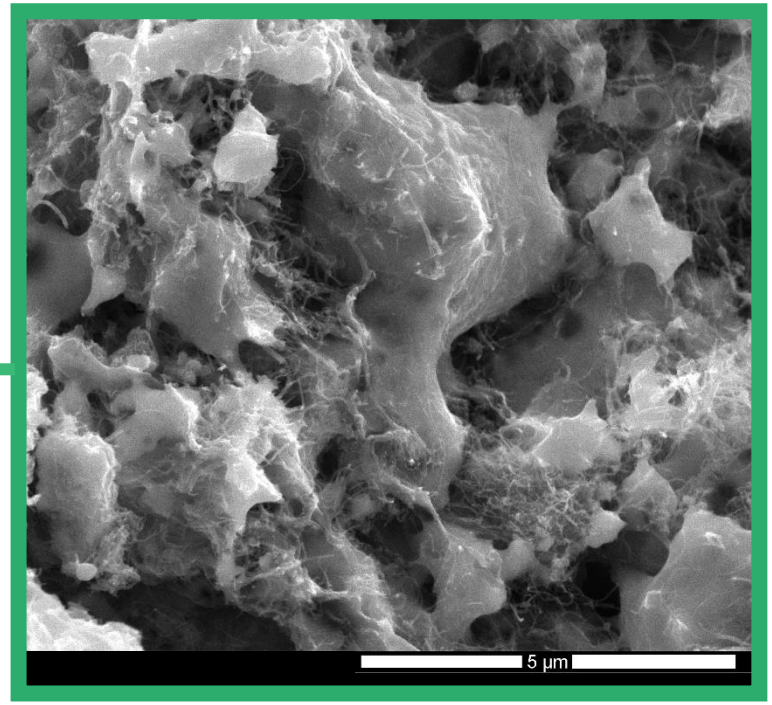
- Cold cathode electronically controlled x-ray tubes are emerging as a new and potentially disruptive x-ray technology that enables lighter and most cost-effective x-ray imaging along with new fixed gantry tomography imaging
- Field Emission devices, particularly Carbon Nanotubes (CNT), demonstrate a very large electron current proportional to their size, up to tens of micro-Amps per single CNT is possible.
- Scaling field-emission devices from tens of micro-amps per single CNT to tens or hundreds of milli-amps with many CNTS has historically been limited to a few milli-amp field emitters.
- Typically, field-emission research has focused on scaling current density to achieve the tens or hundreds of milli-amps for medical imaging and has assumed fixed current for continuous application or fixed set of electron pulse duration.
- Micro-X has patented a unique approach to creating large area and high current field emission devices. In this research, Micro-X investigated the effect of emitter area on the maximum current density, on the maximum sustained current density over life, and on effect of varying pulse durations.

METHODS

CNT Emitter Testing

- Our analysis consisted of testing different sized CNT emitters





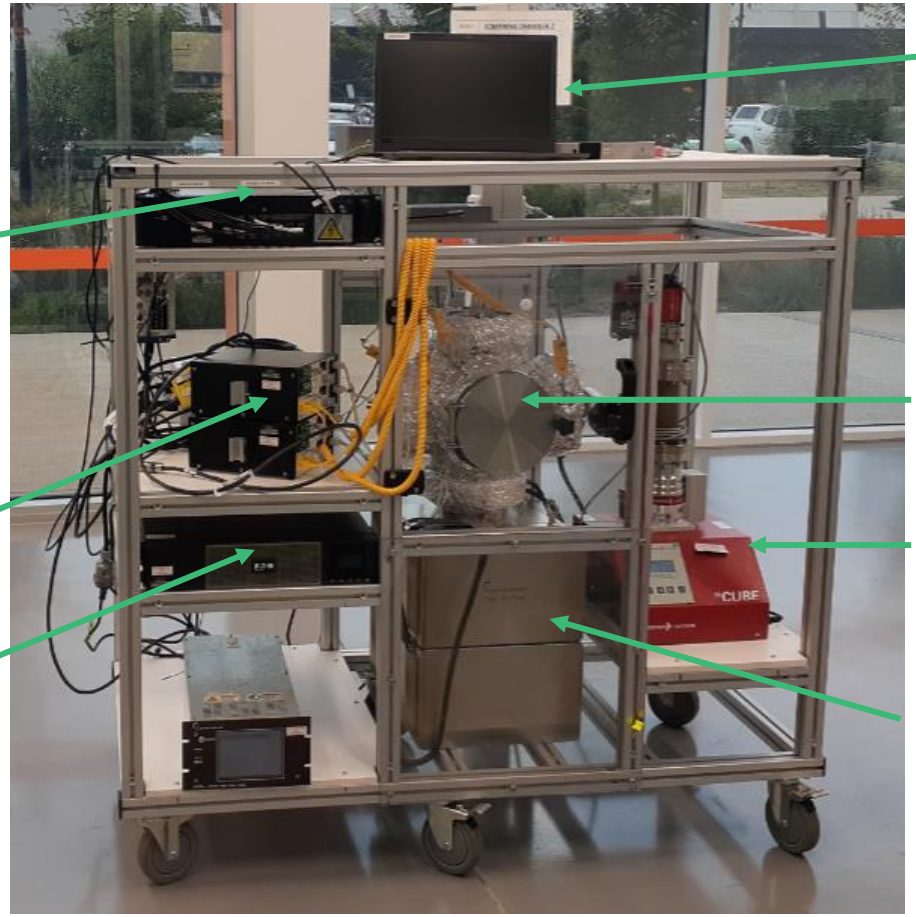
- All emitters were created using the same proprietary method (Patent WO2019191801)
- Emitters were tested in a bespoke vacuum chamber under varying pulse lengths and currents to demonstrate a variety of electric field stress on the CNTs
- Life testing was performed to investigate long term emitter performance.

METHODS

Test Chamber

- CNT were assembled into electron emitters in a cleanroom.
- Subsequent testing took place in a custom-built test vacuum chamber.

Electron Emitter Assembly

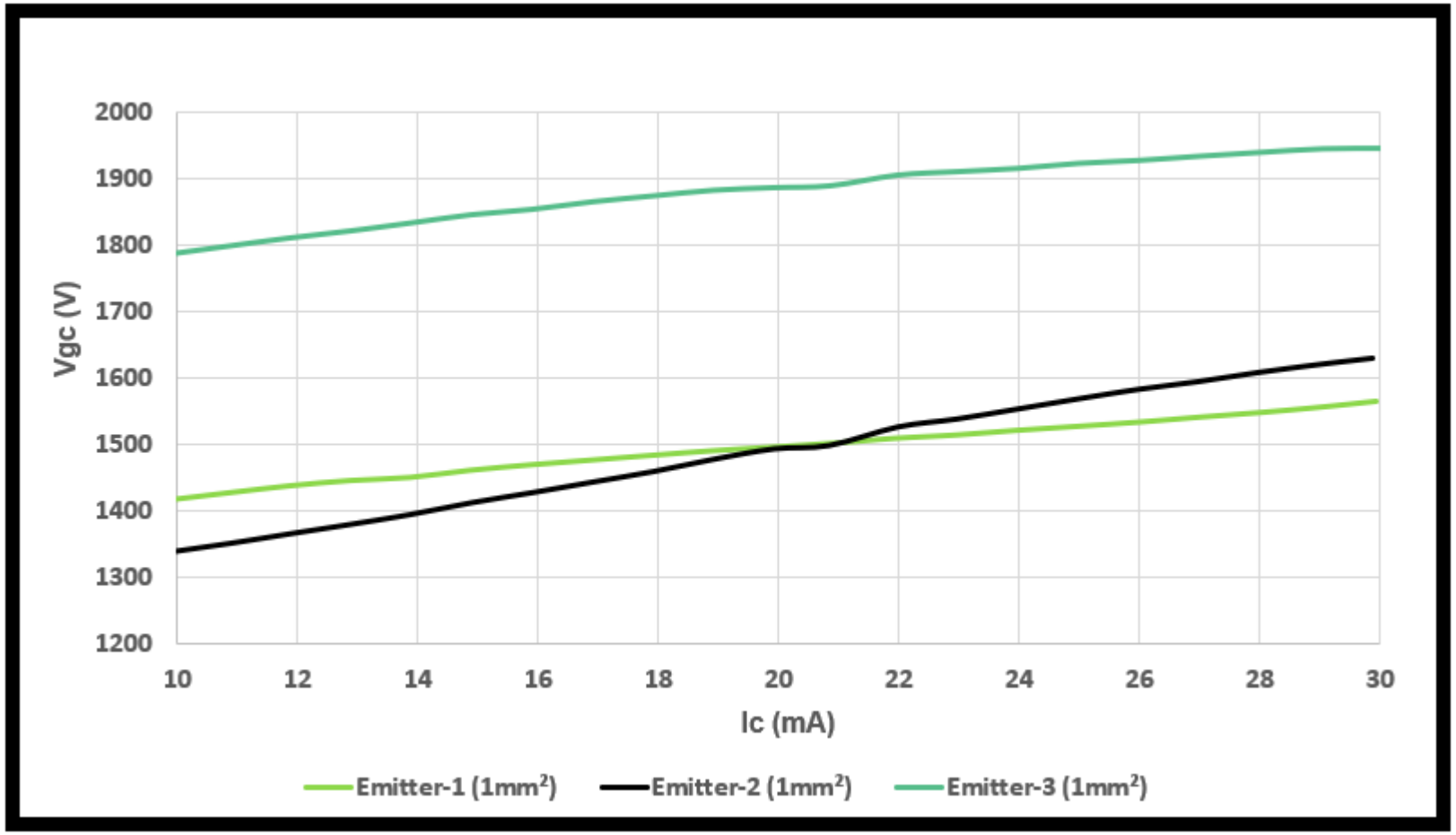


TEST CURRENT DENSITY

CNT Emitter 1 mm²

- Three replicates of 1 mm² CNT emitters

- Increase emitter current in 1mA steps while recording the emitter voltage.
- Each test was for a short 10ms long electron emission pulse.
- Peak current density 30mA/mm²

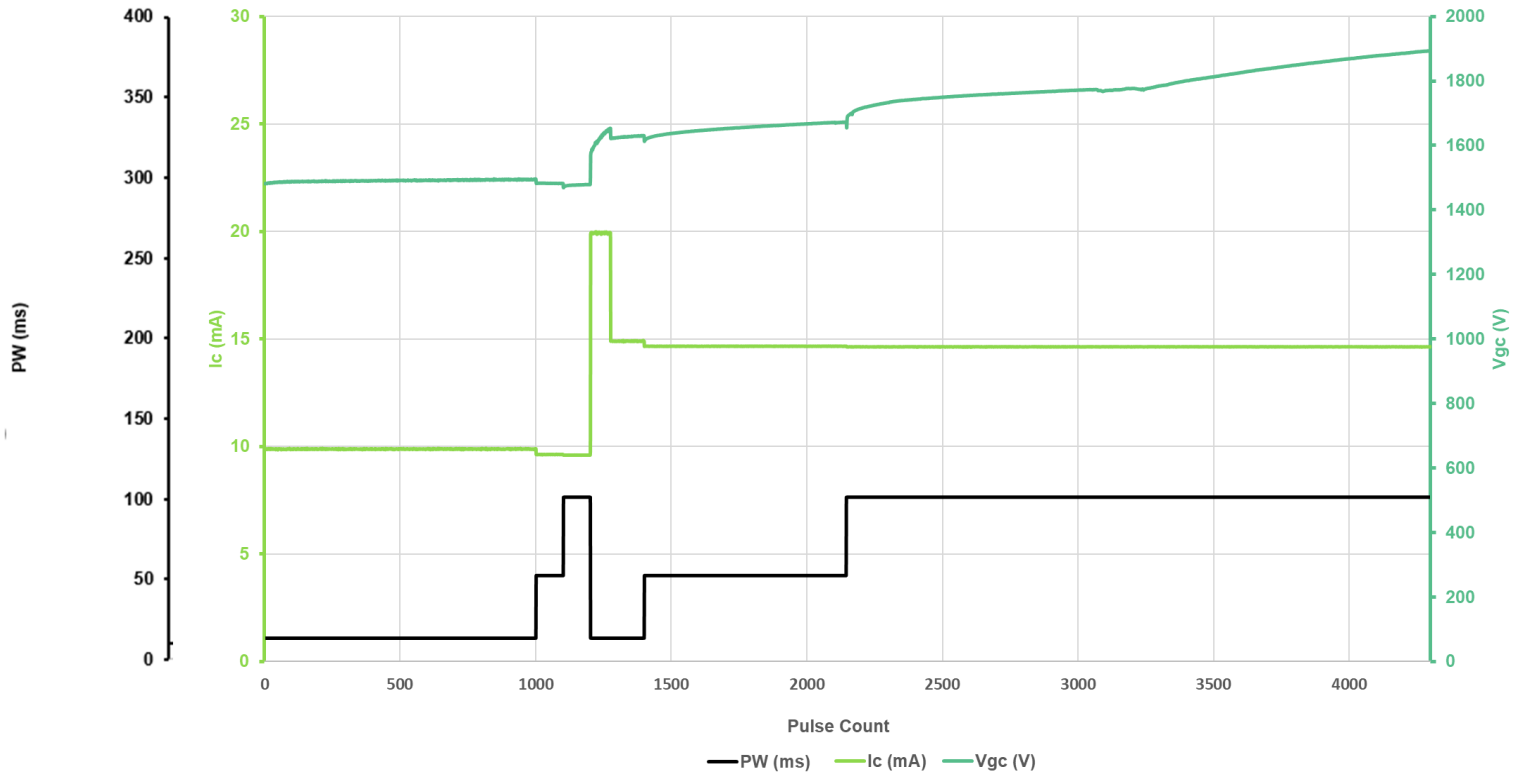


TEST EMITTER LIFE

CNT Emitter 1 mm²

- Test on a 1 mm² CNT emitter

- Vary the current density of the emitter by varying current of pulse.
- Vary pulse width of electron pulse.
- Achieved >4,000 continuous pulses at settings between 10-20 mA/10-100 ms

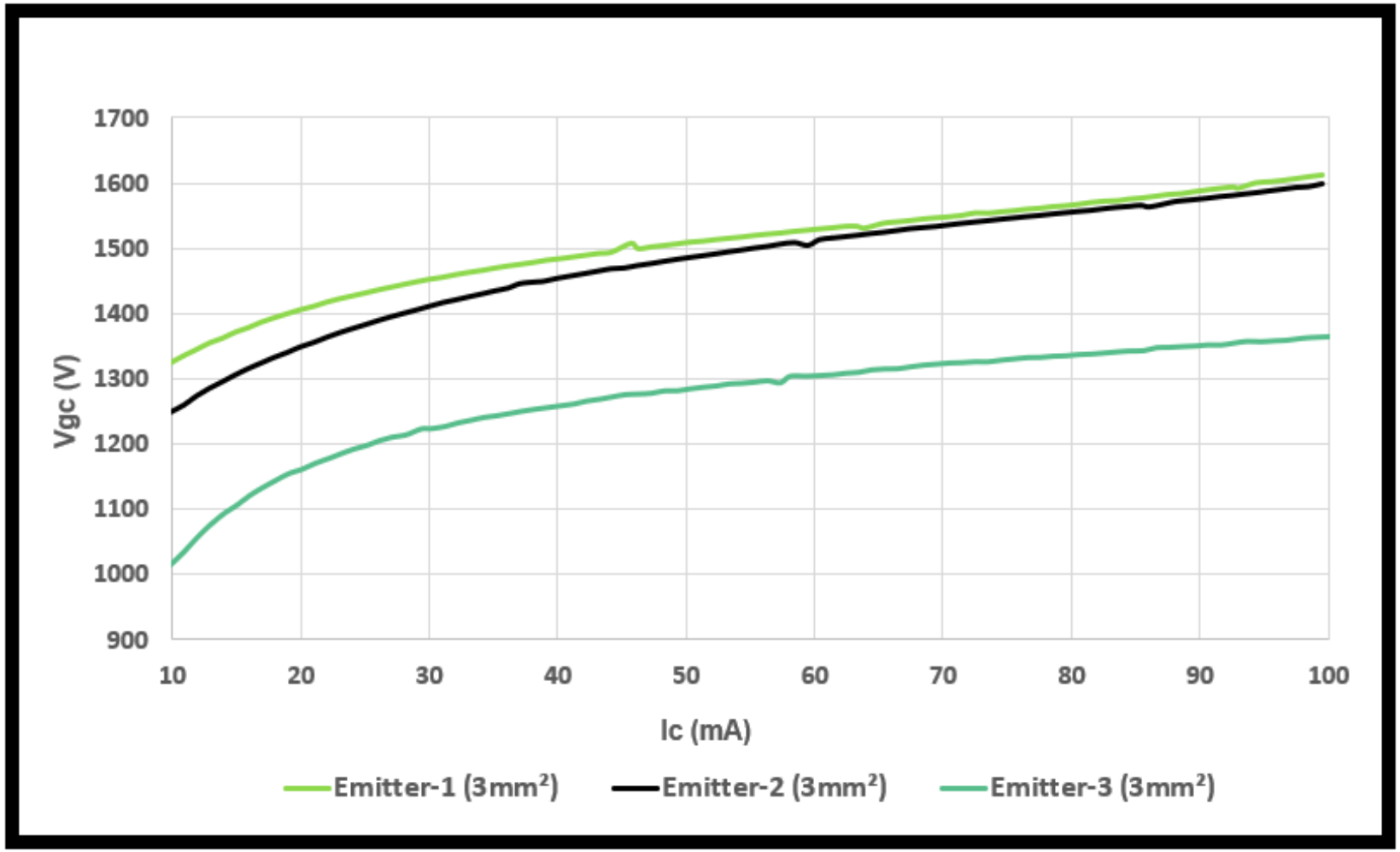


TEST CURRENT DENSITY

CNT Emitter 3 mm²

- Three replicates of 3 mm² CNT emitters

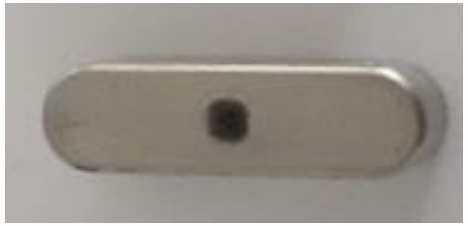
- Increase emitter current in 1mA steps while recording the emitter voltage.
- Each test was for a short 10ms long electron emission pulse.
- Peak current density 33mA/mm²



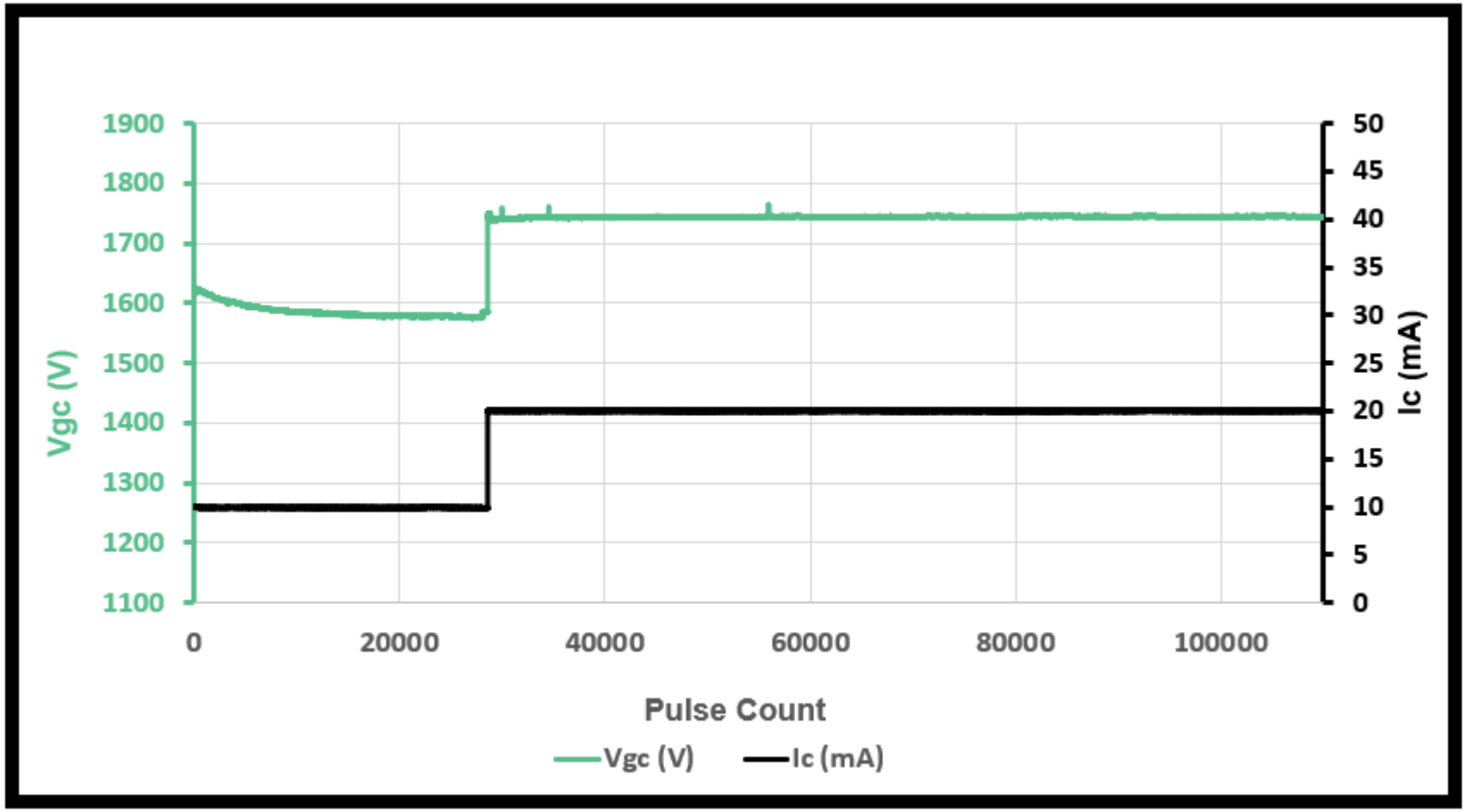
TEST EMITTER LIFE

CNT Emitter 3 mm²

- Test on a 3 mm² CNT emitter



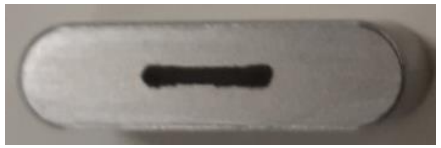
- Vary the emitter current density for fixed pulse-width.
- Achieved >100,000 continuous pulses at settings between 10-20 mA/10 ms



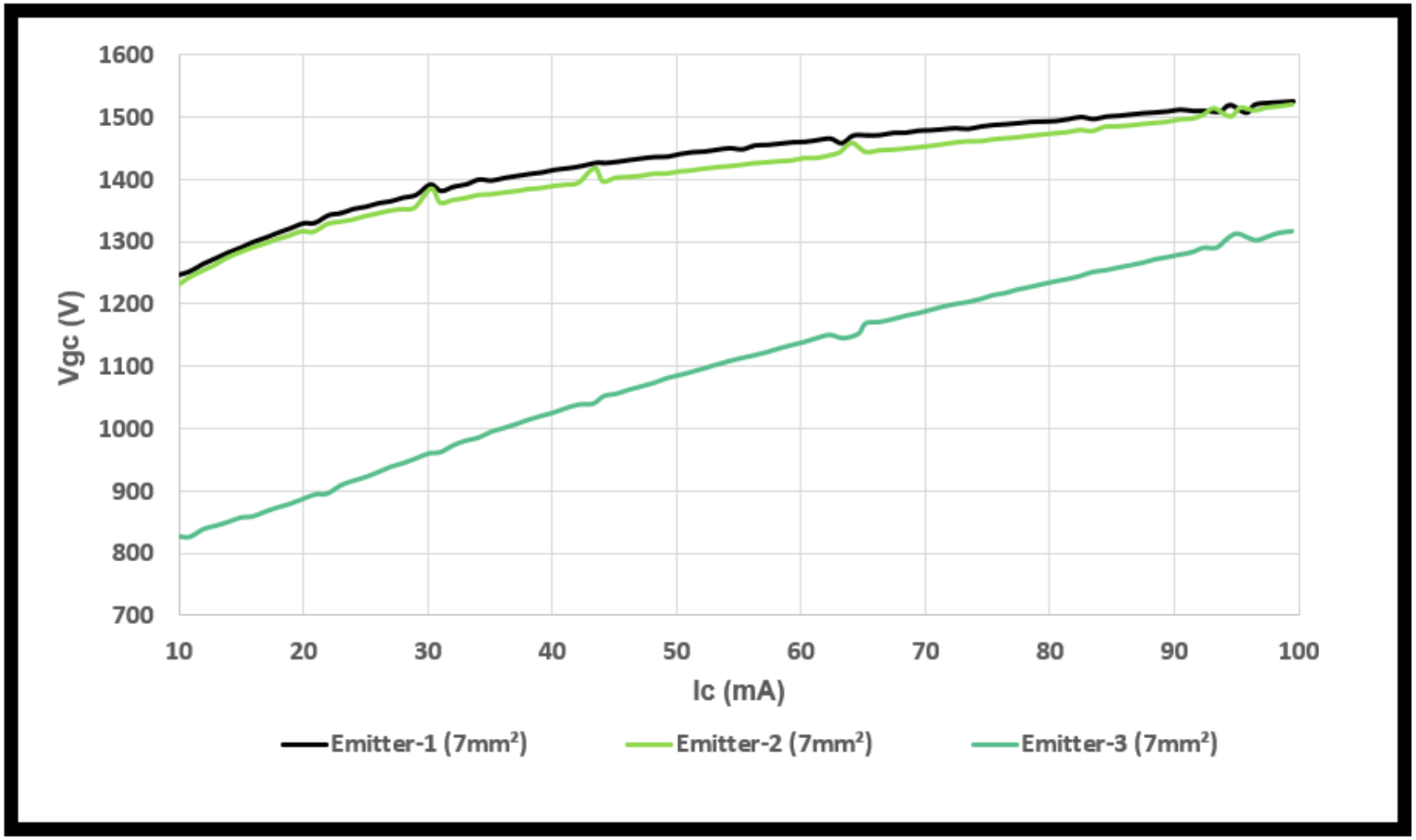
TEST CURRENT DENSITY

CNT Emitter 7 mm²

- Three replicates of 7 mm² CNT emitters



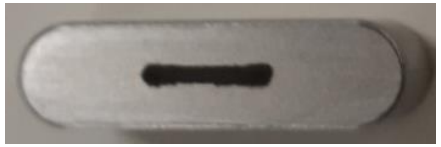
- Increase emitter current in 1mA steps while recording the emitter voltage.
- Each test was for a short 10ms long electron emission pulse.
- Peak current density 14mA/mm²



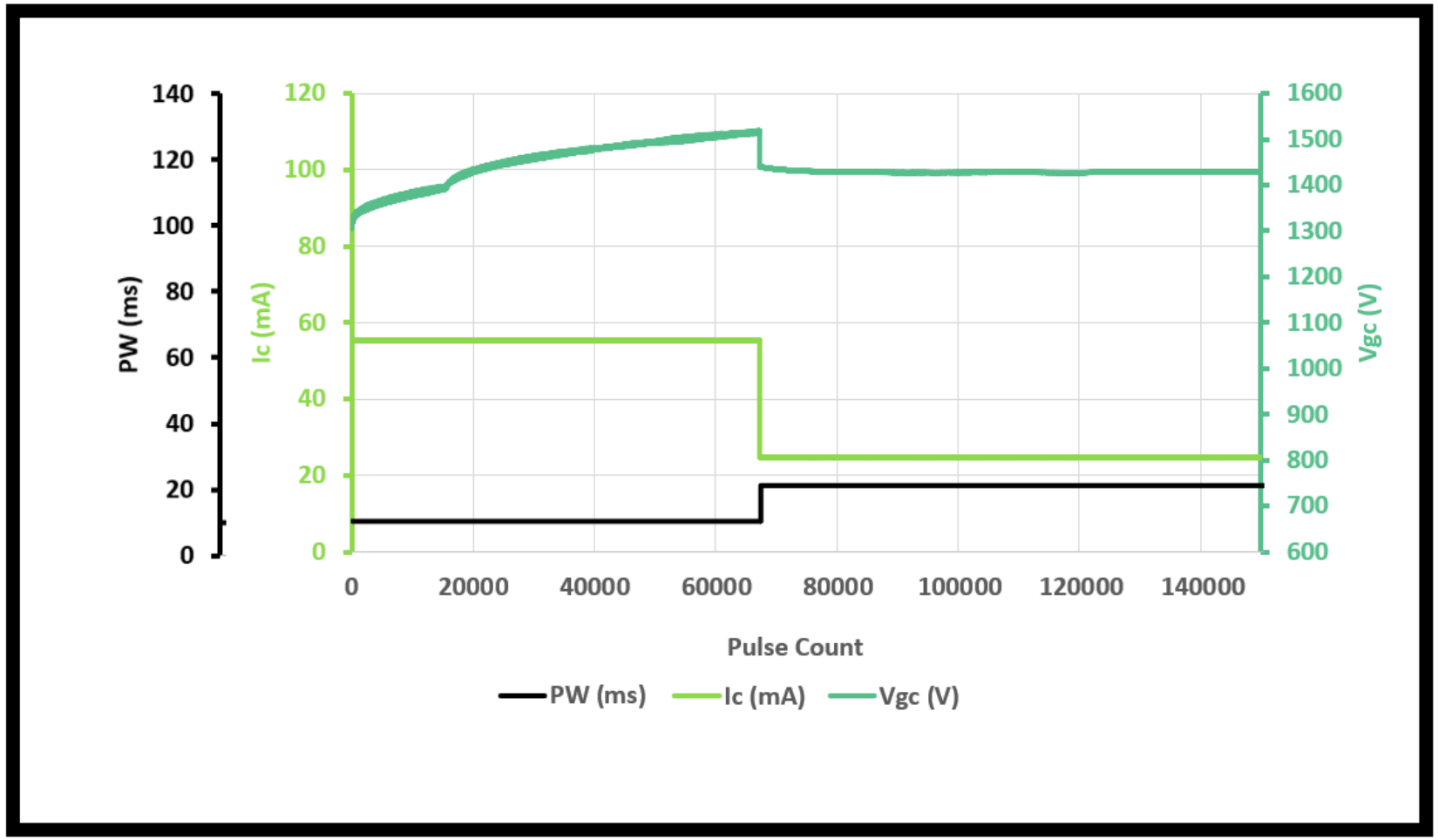
TEST EMITTER LIFE

CNT Emitter 7 mm²

- Test on a 7 mm² CNT emitter



- Vary the emitter current density for fixed pulse-width.
- Achieved >150,000 continuous pulses at settings between 25-55 mA/10-22 ms
- After initial degradation at 55mA/10 ms, the emitter recovered and stabilised at 25mA/22 ms

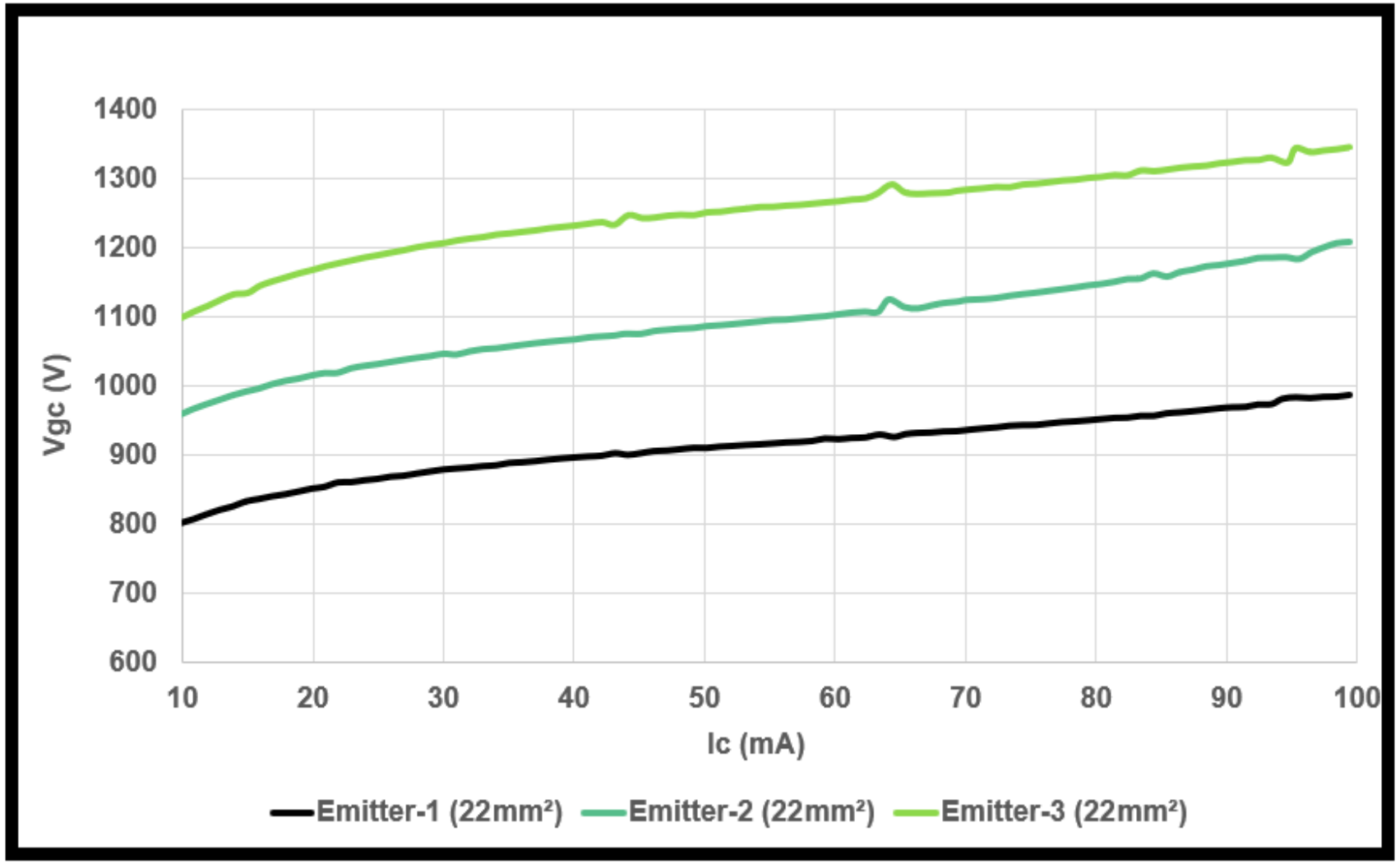


TEST CURRENT DENSITY

CNT Emitter 22 mm²

- Three replicates of 22 mm² CNT emitters

- Increase emitter current in 1mA steps while recording the emitter voltage.
- Each test was for a short 10ms long electron emission pulse.
- Peak current density 4.5mA/mm²

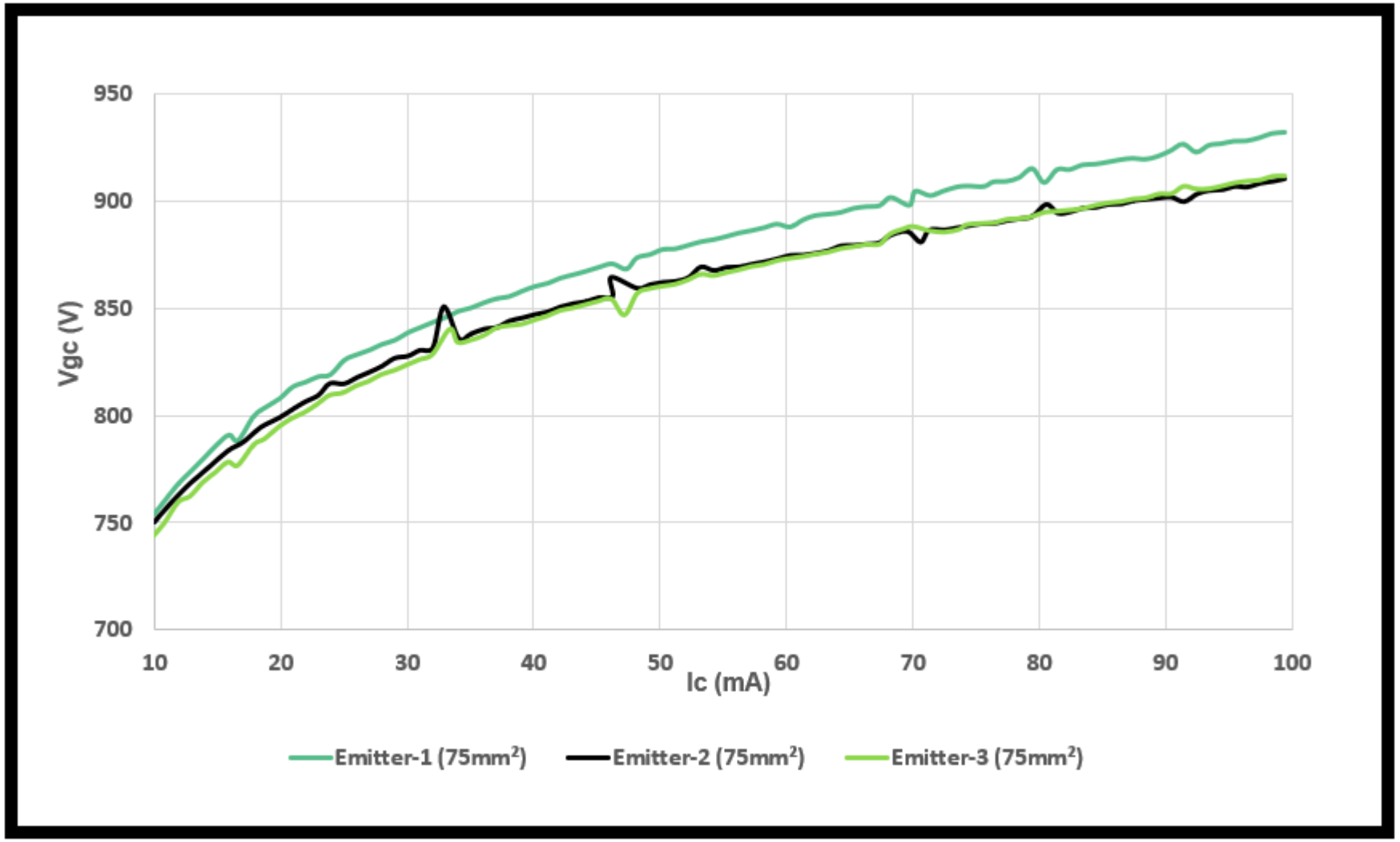


TEST CURRENT DENSITY

CNT Emitter 75 mm²

- Three replicates of 75 mm² CNT emitters

- Increase emitter current in 1mA steps while recording the emitter voltage.
- Each test was for a short 10ms long electron emission pulse.
- Peak current density 1.3 mA/mm²

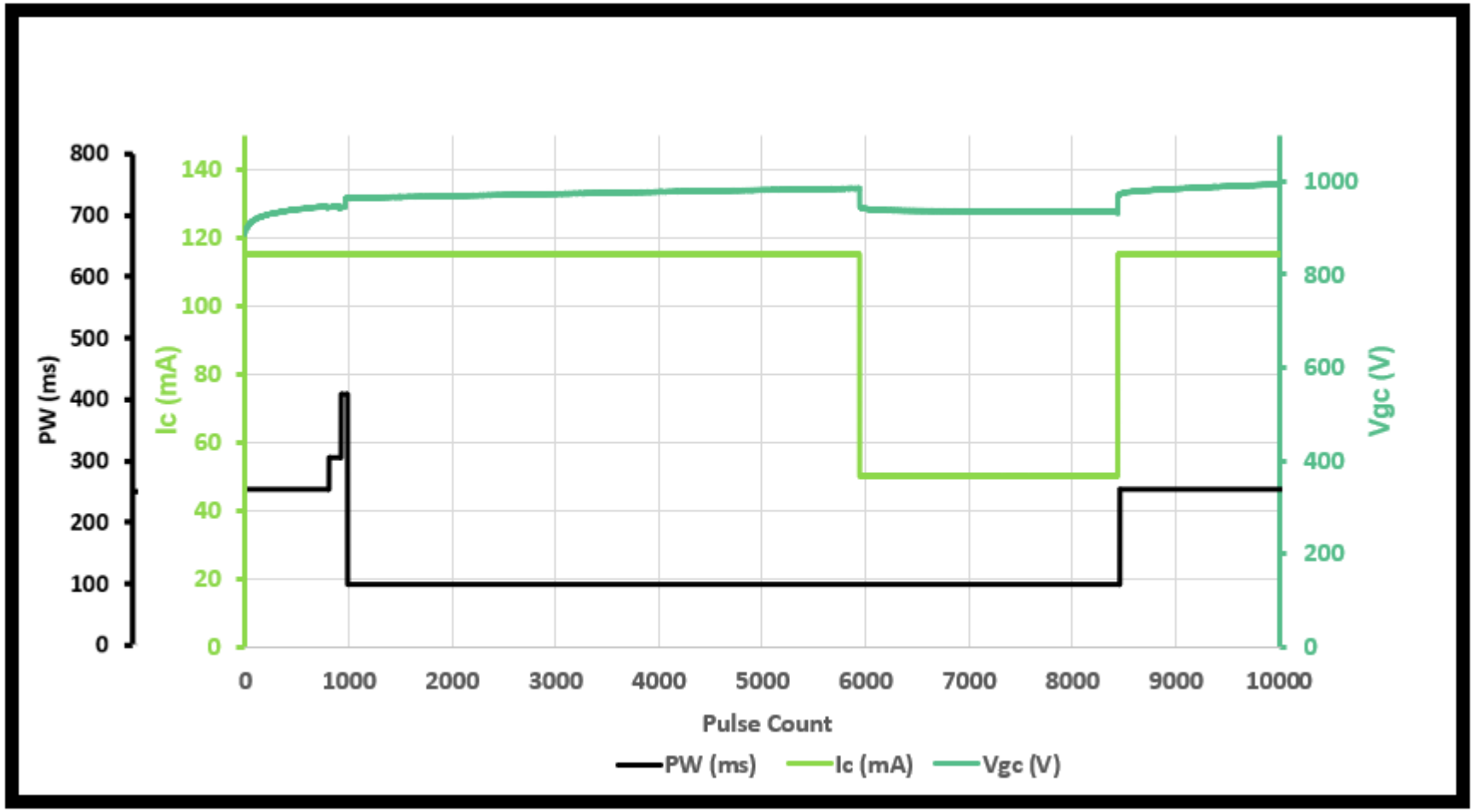


TEST EMITTER LIFE

CNT Emitter 75 mm²

- Test on a 75 mm² CNT emitter

- Achieved >10,000 continuous pulses with settings between 50-115 mA/100-400 ms
- Emitter showed loss of 20 V between 1,000 and 6,000 pulses while running at 115 mA
- Emitter recovered at lower current of 50 mA and gained 10 V between 6,000 and 8,500 pulses

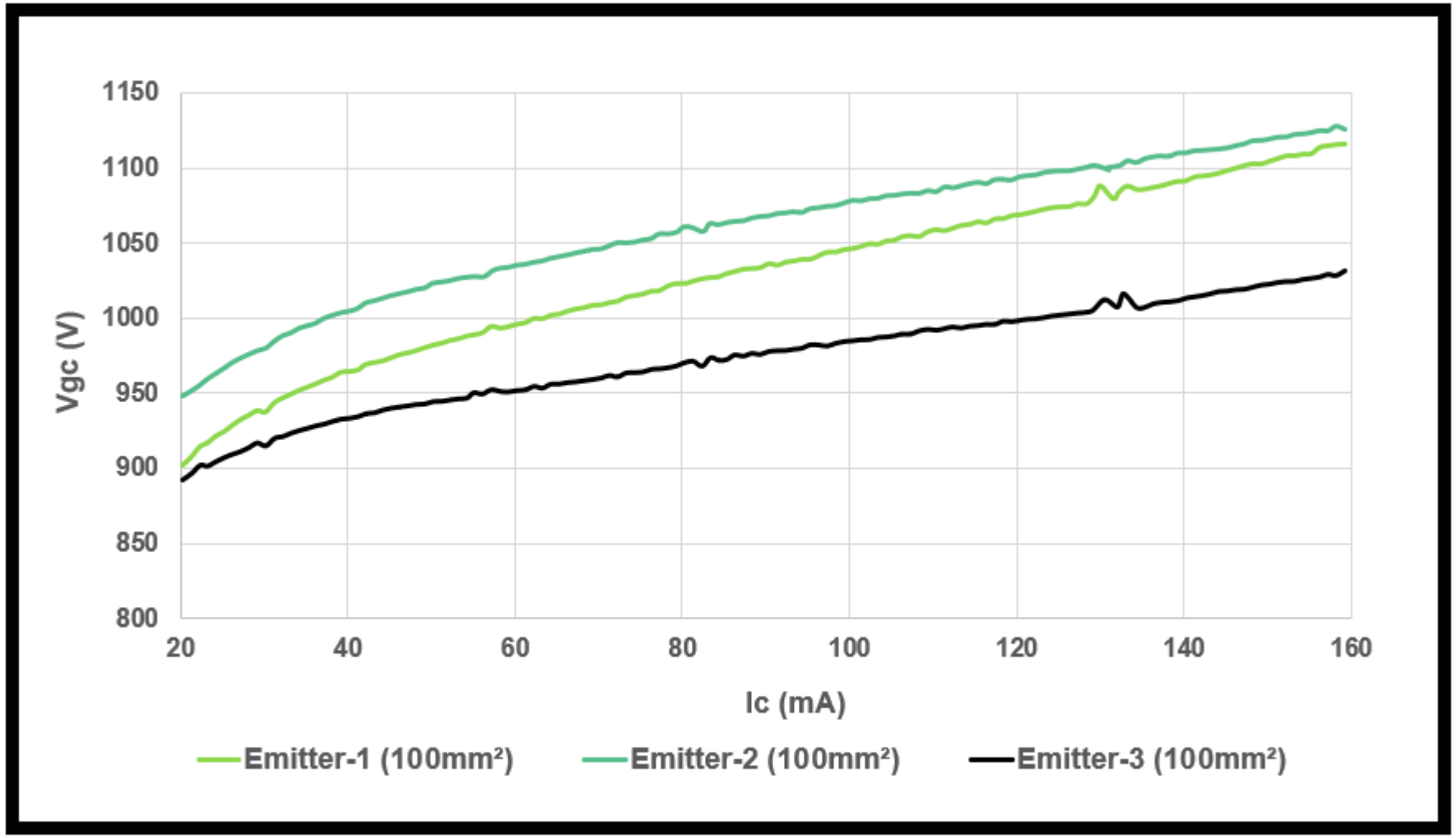


TEST CURRENT DENSITY

CNT Emitter 100 mm²

- Three replicates of 100 mm² CNT emitters

- Increase emitter current in 1mA steps while recording the emitter voltage.
- Each test was for a short 10ms long electron emission pulse.
- Peak current density 1.6mA/mm²

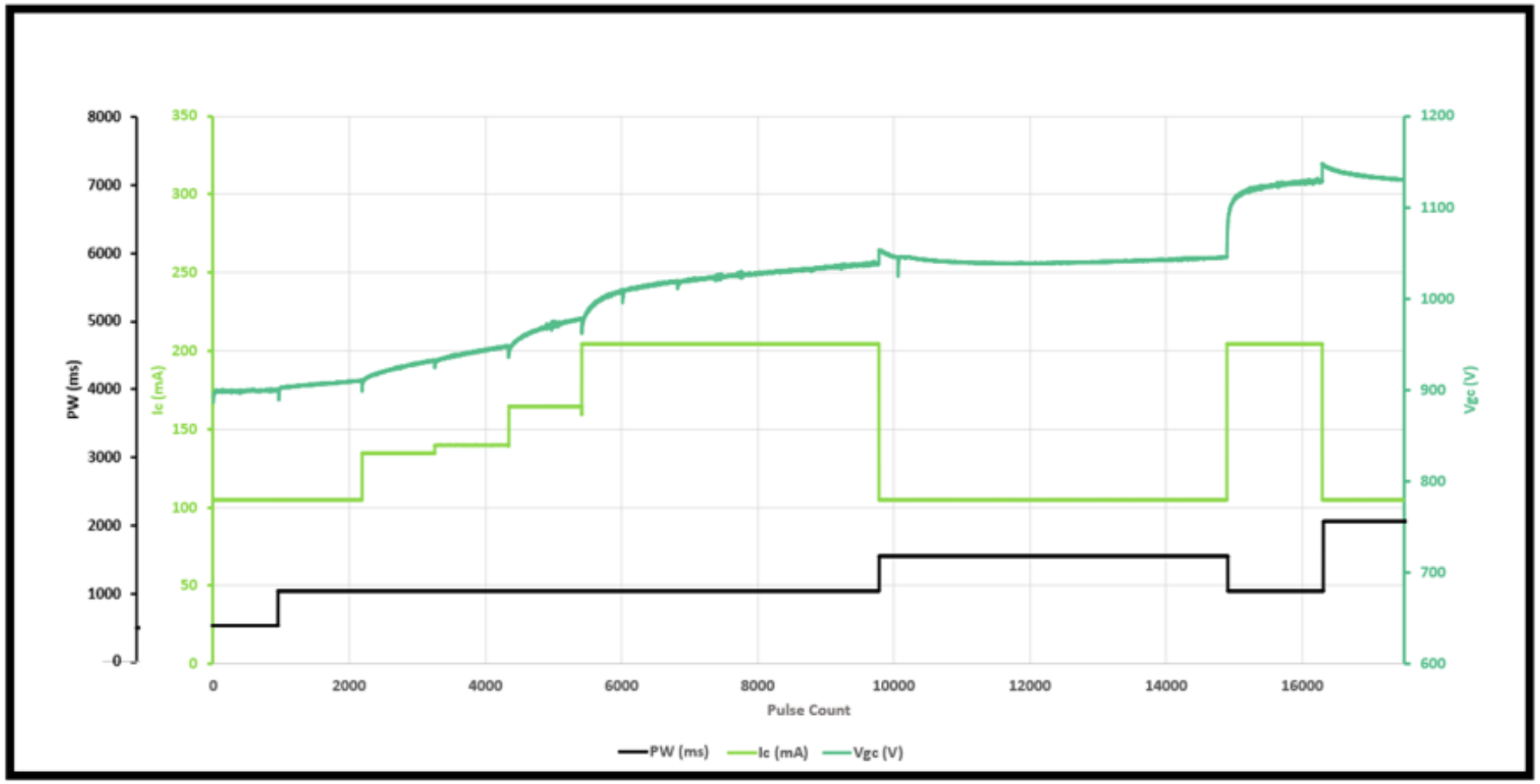


TEST EMITTER LIFE

CNT Emitter 100 mm²

- Test on a 100 mm² CNT emitter

- Achieved >17,000 continuous pulses with settings between 105-205 mA/500-2000 ms
- After initial degradation, the emitter recovered and stabilised at lower current of 105 mA between 10,000 and 15,000 pulses

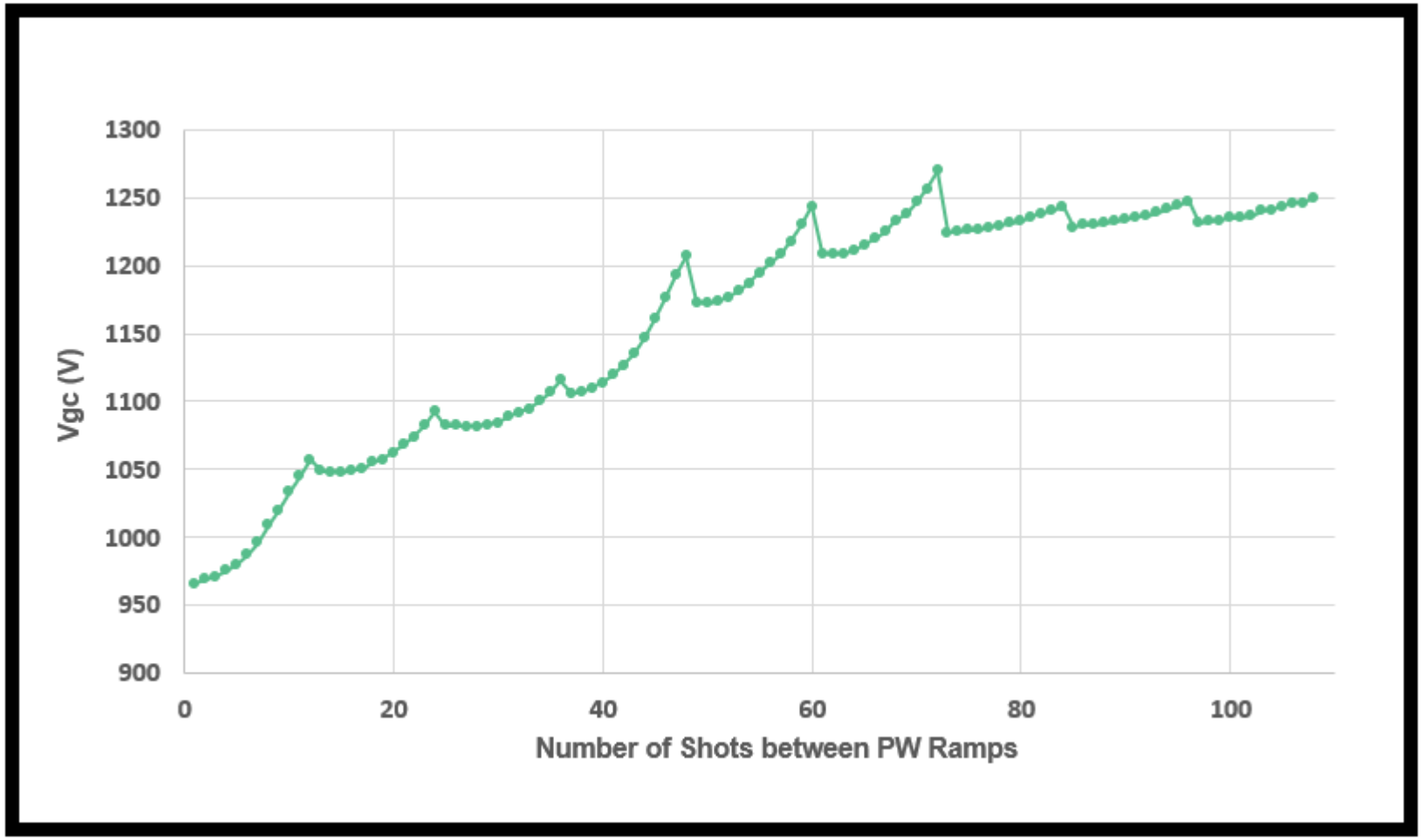


TEST EMITTER LIFE

CNT Emitter 100 mm²

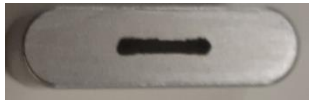
- Test on a 100 mm² CNT emitter

- Performed 3 x 36 pulsewidth (PW) ramps at 10-500 ms, 500-1,500 ms and 10-500 ms
- Single pulses of 100 mA/25 ms were recorded between each PW ramp
- After initial degradation during the first two sets of PW ramping, the emitter recovered and stabilised during the third PW ramping



RESULTS

CNT Emitter Test Data Summary

Emitter	Size (mm^2)	Maximum Test Current	Maximum Sustained Current	Maximum Pulse-Widths
	1	30mA	10mA	100ms
	3	100mA	20mA	10ms
	7	100mA	55mA	10ms
	22	100mA	-	-
	75	120mA	120mA	250ms
	100	200mA	200mA	1 second

CONCLUSION

CNT Emitter

- Micro-X unique CNT emitter provides high current density over multiple sized emitters.
- Testing of peak current limited by the power supply, original only went to 120mA second went to 200mA.
- Long term achievable current is a function of:
  - Emitter size – current density of emitter
  - Pulse-Width – current density changes for longer emitters
  - Targeted lifetime of emitter – can run higher current for shorter lifetimes
- CNT Emitter demonstrates “recovery” performance – when emitter field-emission is relaxed from a high stress condition, the emitter degradation stops and emitter appears to recover.
- CNT Emitter demonstrates “learning” performance – as a high stress test is performed repeatedly, the performance of the emitter improves over time.

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THANK YOU