Fundamental aspects of Deep UV Light emitting diodes and failure reduction of LEDS grown on AlN Substrates

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Crystal IS™
High Performance UVC LEDs

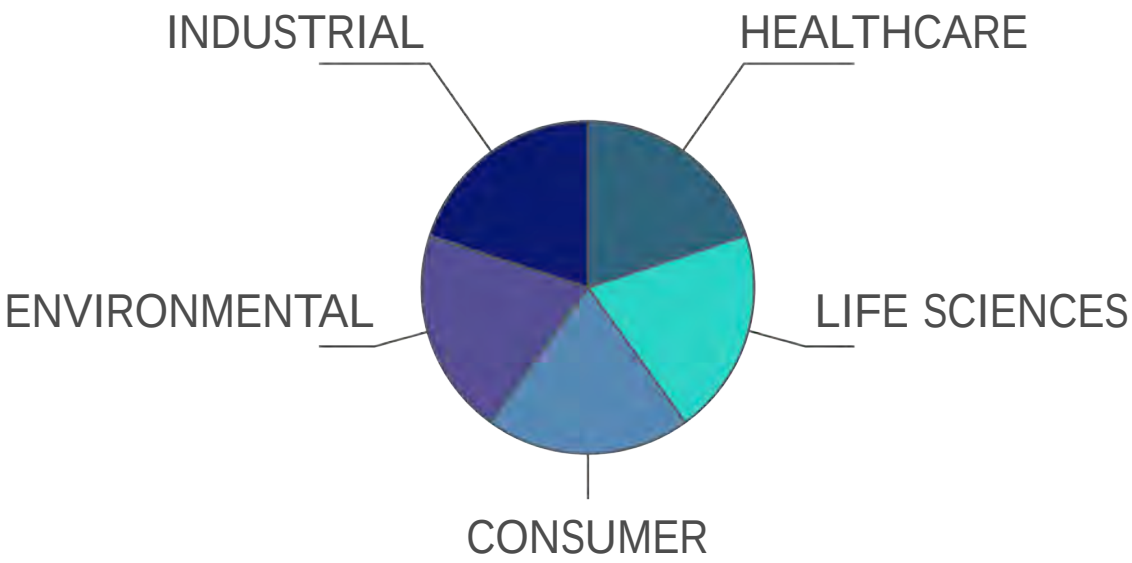
Outline

- Introduction
- III-V Technology for UV LEDs
- UVC LED fabrication
- Device Reliability
- Summary

WE ARE CRYSTAL IS

- Location: Green Island, NY
- Employees: 50 employees
- Technology: *From crystal growth to packaged die*
  - Aluminum Nitride (AlN) crystal growth
  - Die fabrication
  - Packaged UVC LEDs
  - 34 Patents
- Products:
  - Optan: High spectral quality and long lifetimes for measurement and monitoring.
  - Klaran: High power and compact footprint for disinfection of air, water and surfaces.
- ISO 9001:2008 Certified Company

UVC LED Markets and Advantages



UVC LEDs are:

- Compact
- Safe and environmentally friendly
- Instantaneous
- Long-lasting
- Wavelength specific

The future of these devices is dependent on offering:

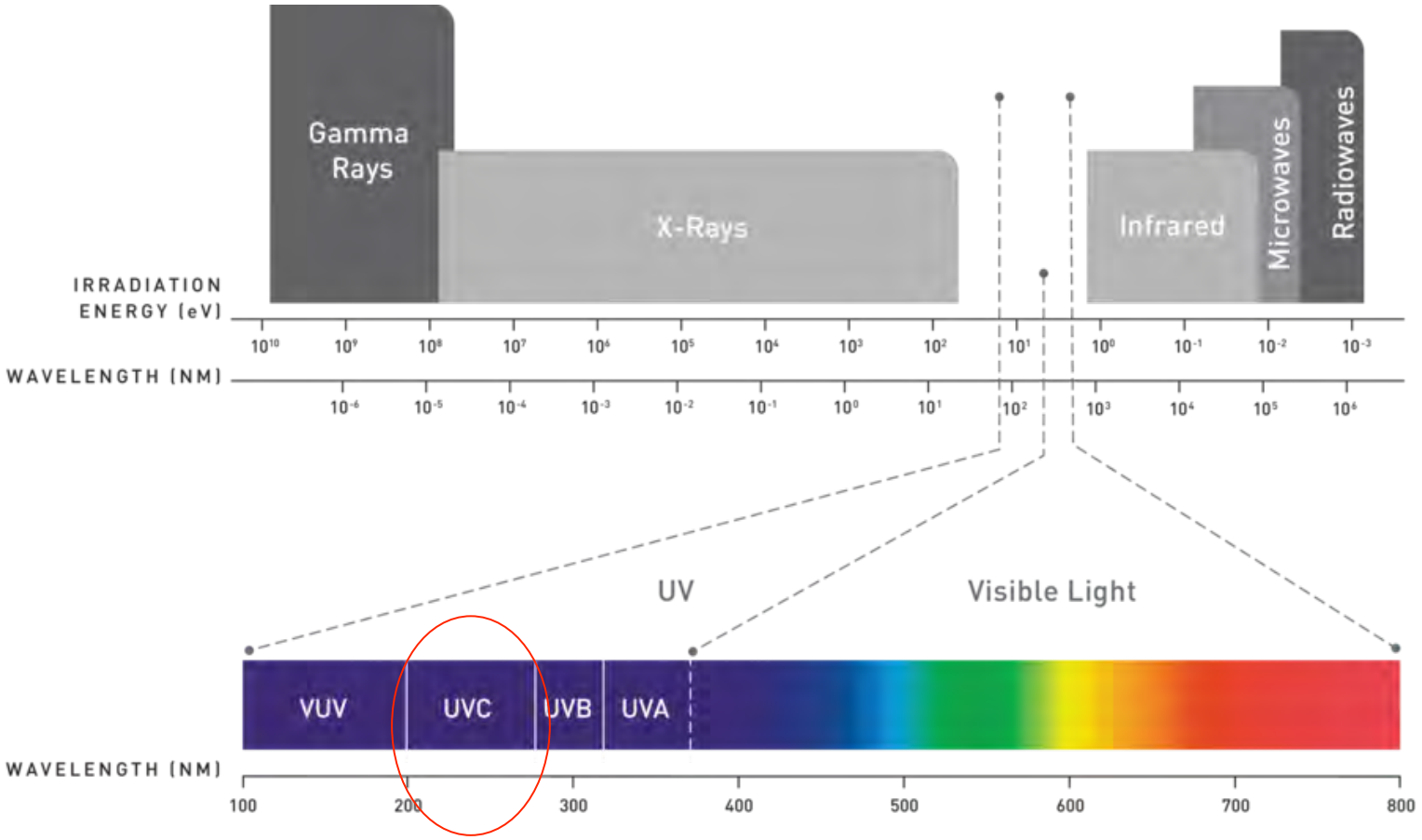
- High power
- Long lifetime

OUR PRODUCT OFFERINGS

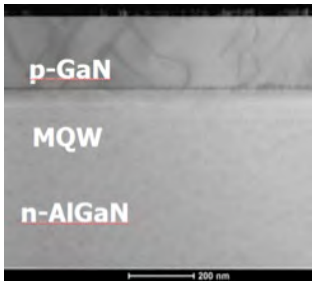
	Optan	Klaran
Application	Instrumentation	Disinfection
Package	TO-39 and SMD	SMD
Output power	1-5 mW	> 20 mW
Lifetime	3000 hours @ 100 mA	> 1000 @ 400 mA
Wavelength	5 nm bins from 250 – 280 nm	250 - 280 nm
Output angle	15°; 100°; 115°	105°

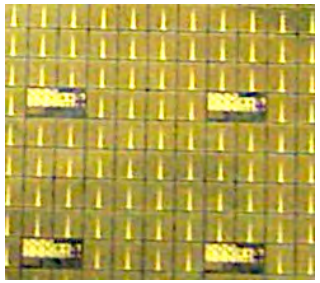
We are developing products to meet the performance requirements of our customers.

Radiation Spectrum



OUR MANUFACTURING PROCESS





AlN Crystal Growth → Substrate Processing → Epitaxial Growth → Device Fabrication → Packaging

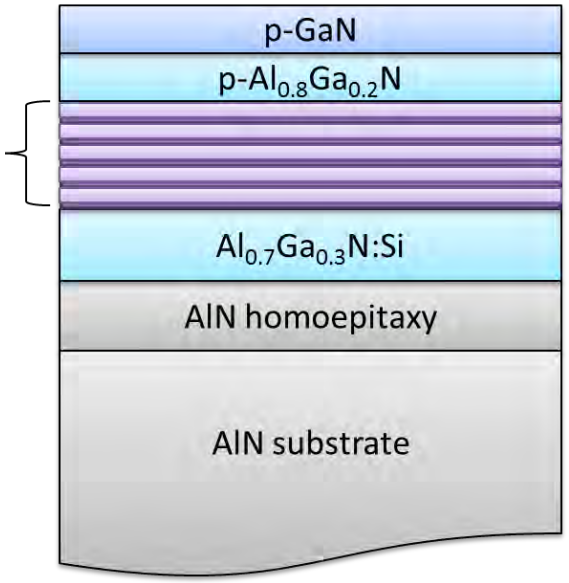
Crystal IS
Green Island, NY, USA

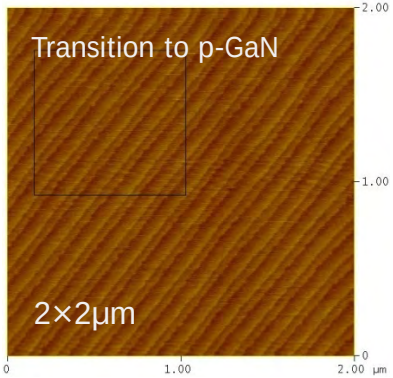
Asahi Kasei Microdevices
Fuji, Japan

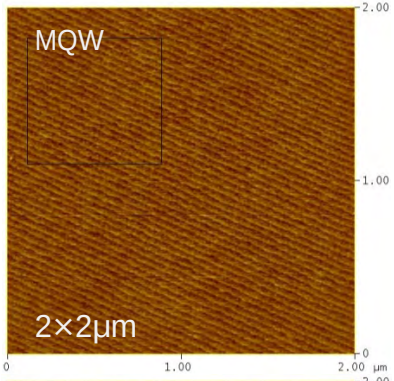
Outsourced Contract Manufacturing

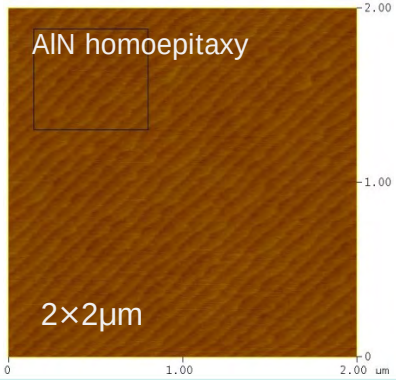
We deliver long-life, high performing LEDs with a well-controlled supply chain and industry-leading production facility.

Our Approach: Pseudomorphic UV LED (PUVLED) Structure









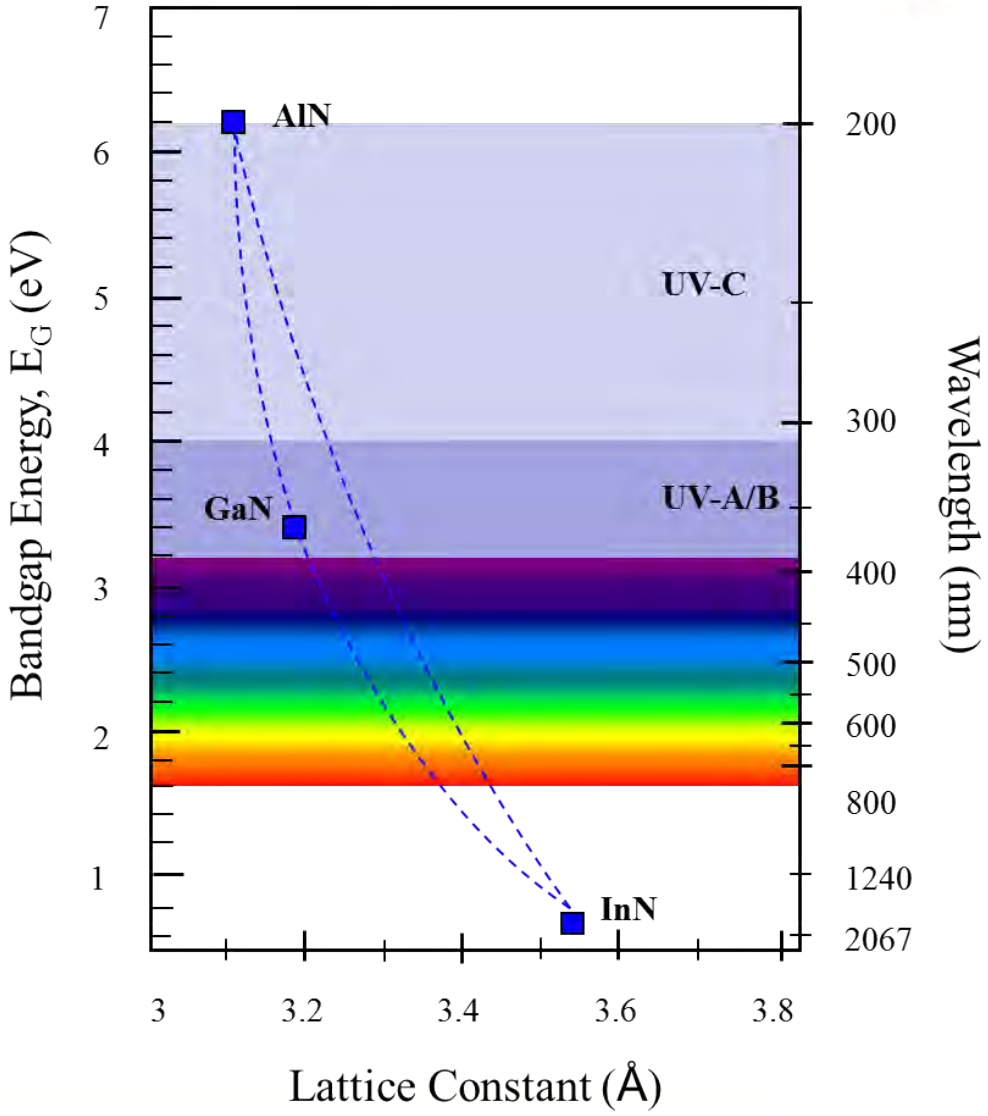
We have demonstrated smooth surface morphology throughout our device structure

Starting AlN substrate surface finish is critical!

Cathodoluminescence confirms TDD density in MQW < 10^5 cm^{-2}

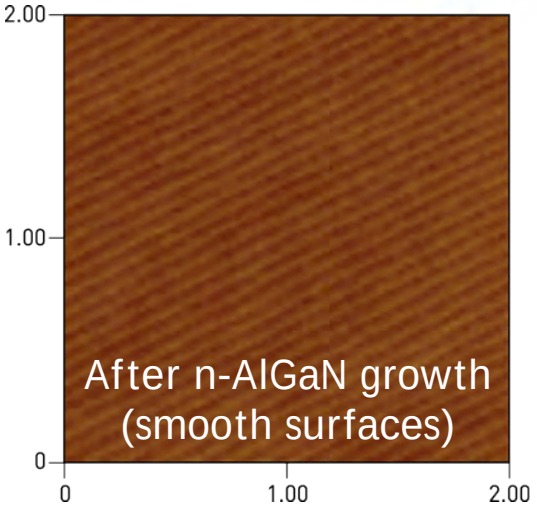
ADJUST THE BAND GAP TO GET THE SPECIFIC WAVELENGTH DESIRED

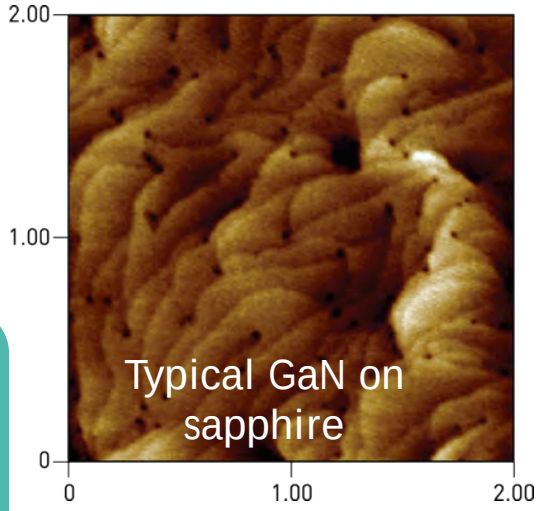
- Bandgap increases with increasing Al concentration.
- Wavelength, $\lambda = 1240/E$



Crystal IS Advantage :: Bulk AlN for UVC LEDs

- Low dislocation density enables high performance
- Transparent to UV-C radiation
- High thermal conductivity (~3 W/cm-K)
- Using bulk AlN substrate for AlGaN semiconductor devices mimics traditional semiconductor processing
  - Easier to scale at larger diameters





Bulk AlN allows for more reliable devices with longer lifetimes and higher power than other substrates.

RELIABILITY AND LIFETIME MEASUREMENTS

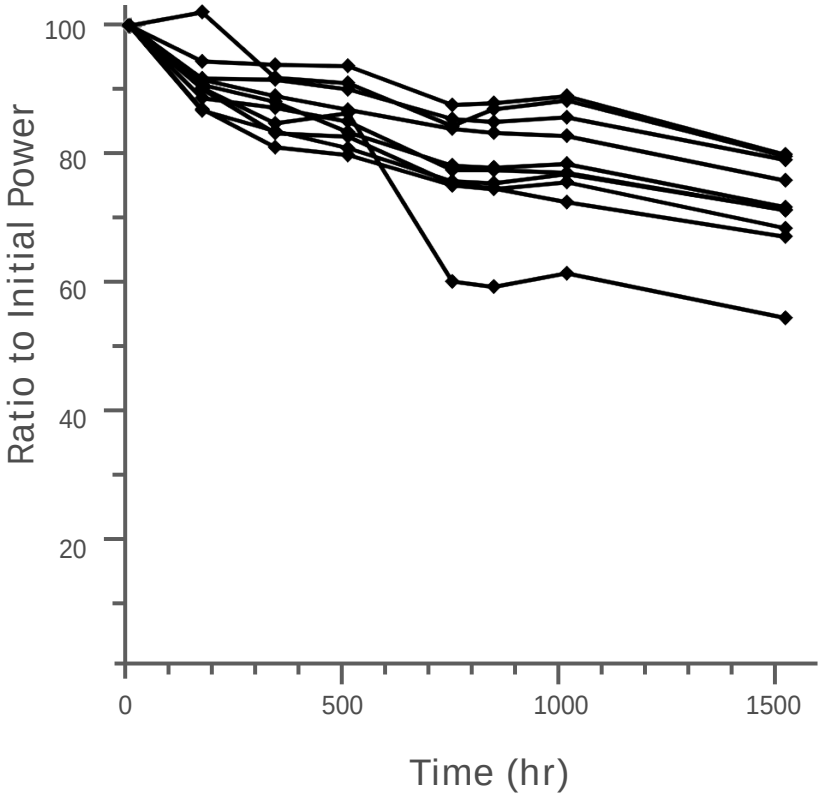
Experimental Procedure

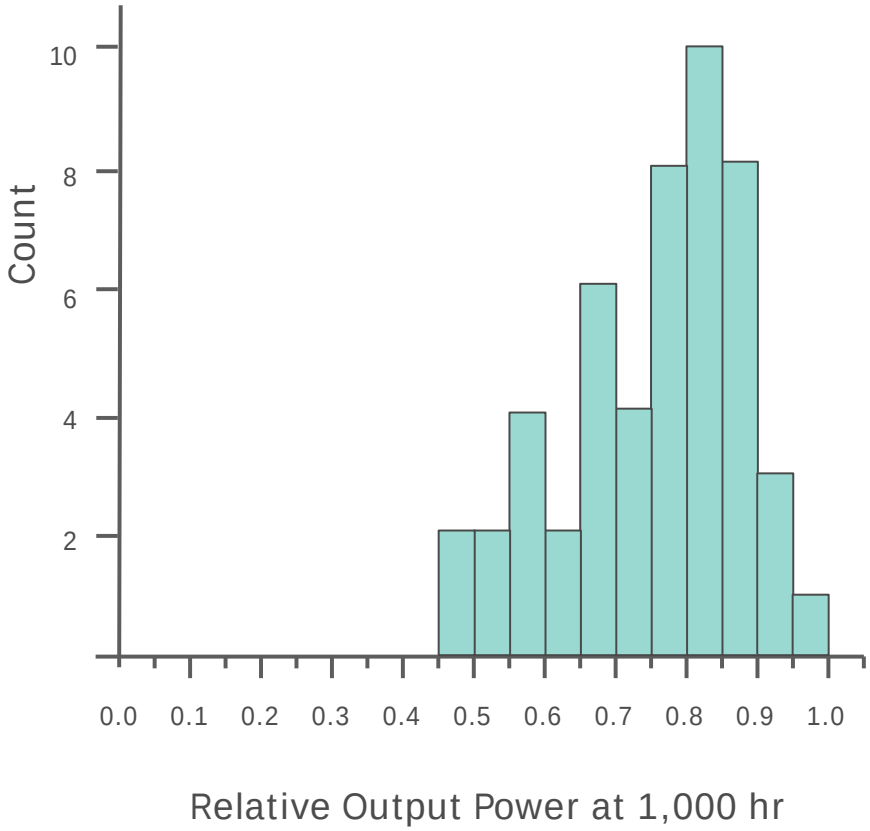
- Lifetime testing was performed on fabrication lots of 10 to 20 Optan® devices per test
  - Each fabrication lot consists of LEDs from multiple substrates and multiple epitaxial runs
- Temperatures described are case temperatures unless otherwise specified
  - Junction temperatures can be estimated from measured package capability

UVC LED Products Tested

	Optan TO-39	Optan SMD
Application	Spectroscopy	Biofilm Prevention
Package	TO-39	SMD
Output power	1-5 mW	> 2 mW
Lifetime	3000 hours @ 100 mA	3000 hours @ 100 mA
Wavelength	5 nm bins from 250 – 280 nm	260 - 275 nm
Output angle	15°	100°

The Lifetime of Crystal IS Optan LEDs

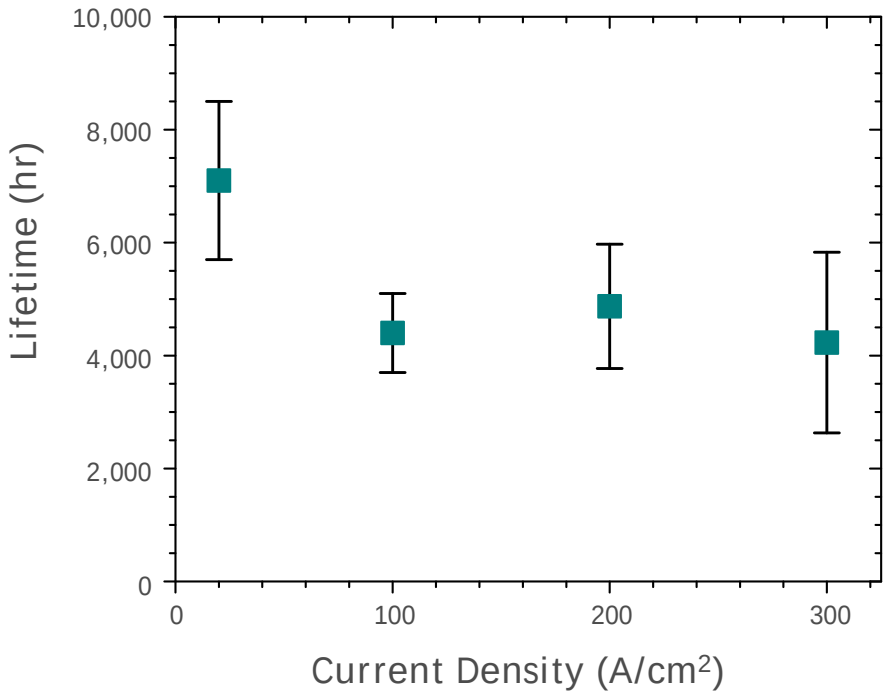




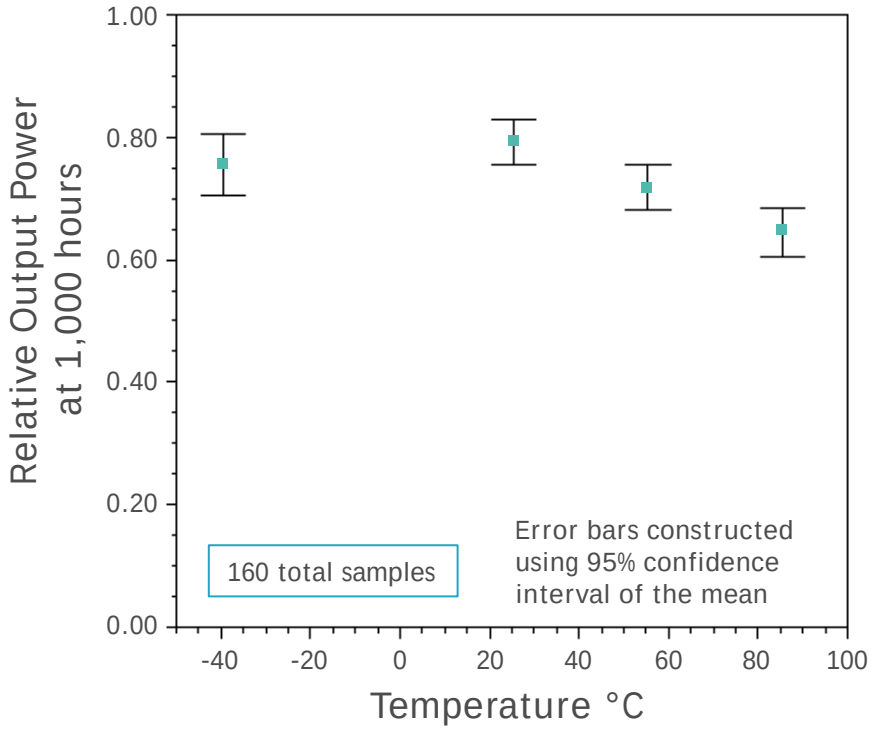
Lifetime >> 1000 hours

Projected Optan Lifetime

- Parts tested to a minimum of 1000 hours with data taken roughly every 150 hours.
  - First 300 hours of data eliminated before evaluating with the model
- Degradation is modeled as with the visible TM-21 standard, an exponential least squares fit of relative output power versus time



Temperature Dependence at 100 mA



- Degradation increases with increasing temperature (0.25 % per °C above room temperature)
- Greater than expected degradation at -40 °C (corresponding to higher reverse leakage at -5 V)

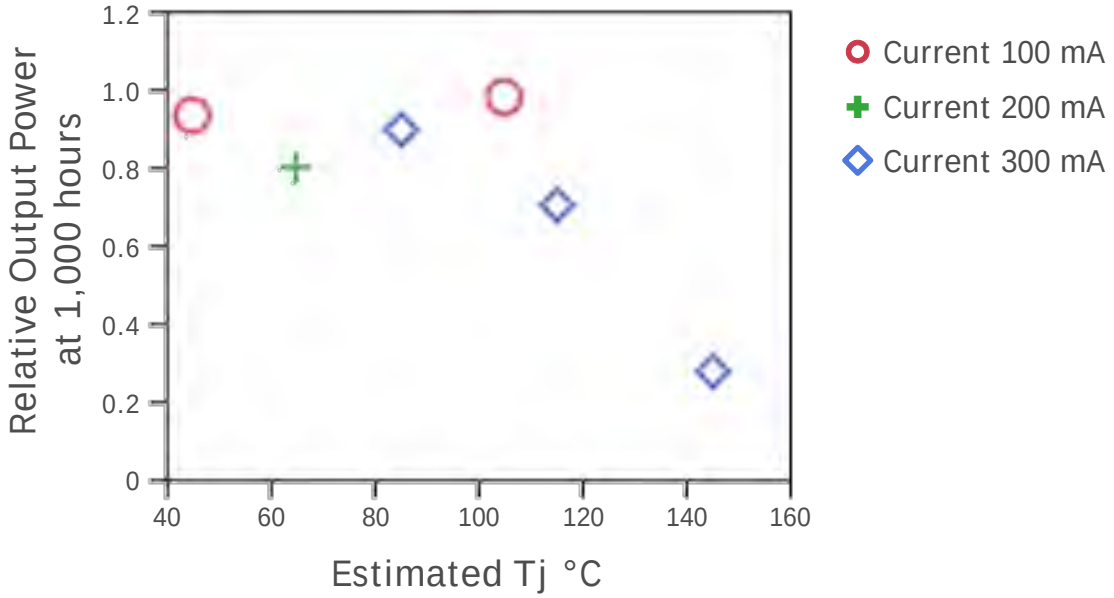
Accelerated Testing

- Devices operated at various case temperatures and current to accelerate the degradation and failure of the LEDs.
  - Three case temperatures and three currents with devices from three different lots

Case Temperature (°C)	Current (mA)	# of Devices
25	100	40
25	200	20
25	300	30
55	300	30
85	100	30
85	300	30

Accelerated Testing Results :: Degradation

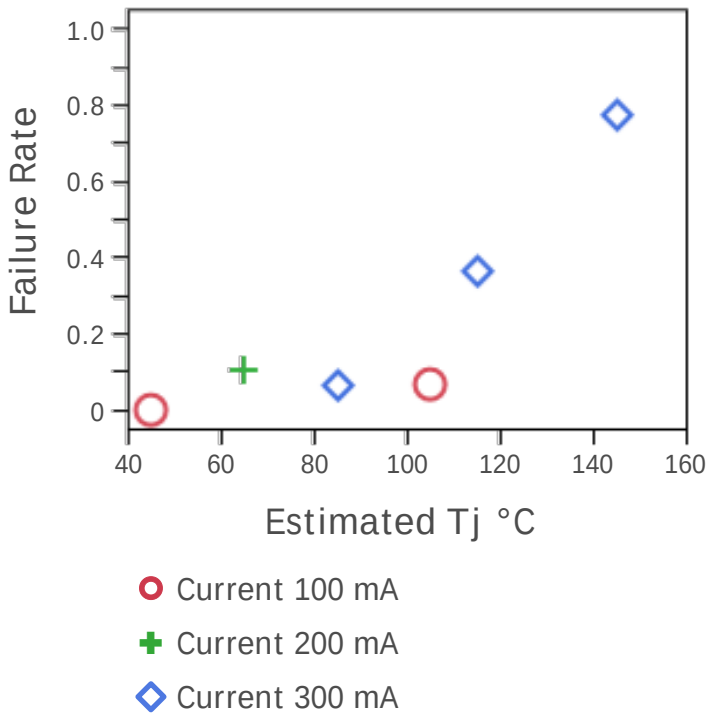
Junction temperature (Tj) estimated from thermal resistance, input power and case temperature.

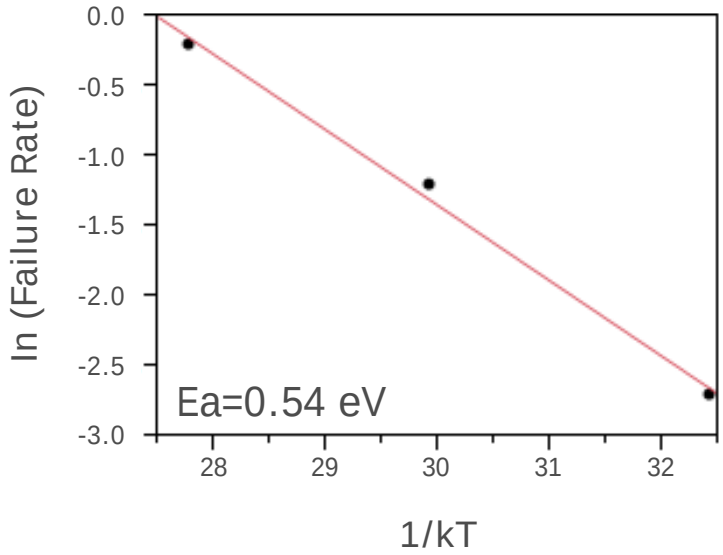


Accelerated degradation only seen at high junction temperatures.

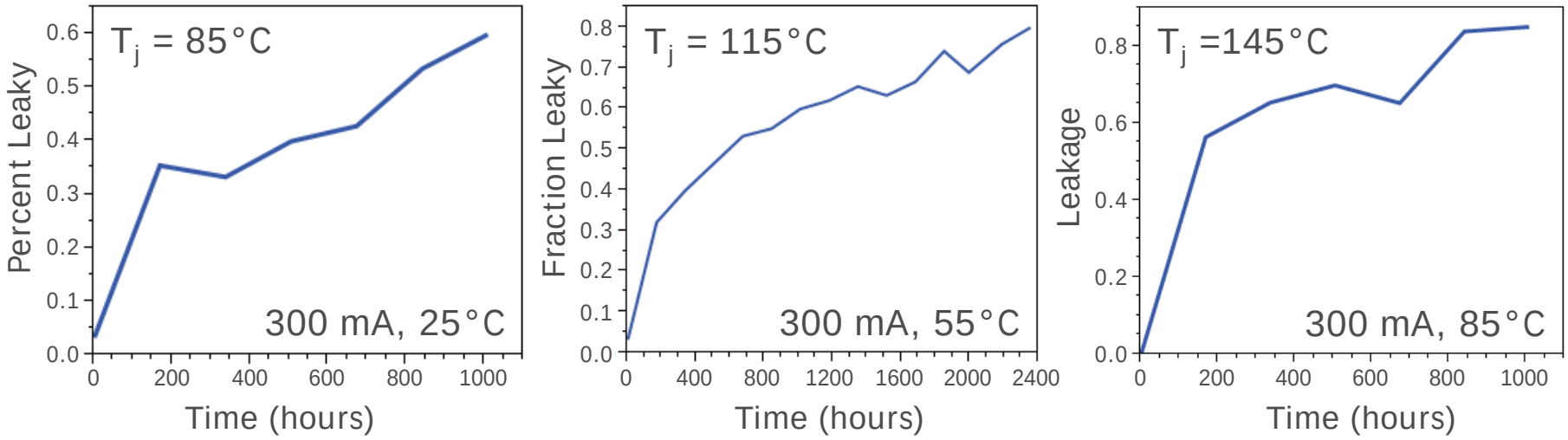
Accelerated Testing Results :: Failure

- Failure rate in 1000 hours (fraction of devices <50% of initial power at 1000 hours)
- Activation energy calculated from 300 mA data





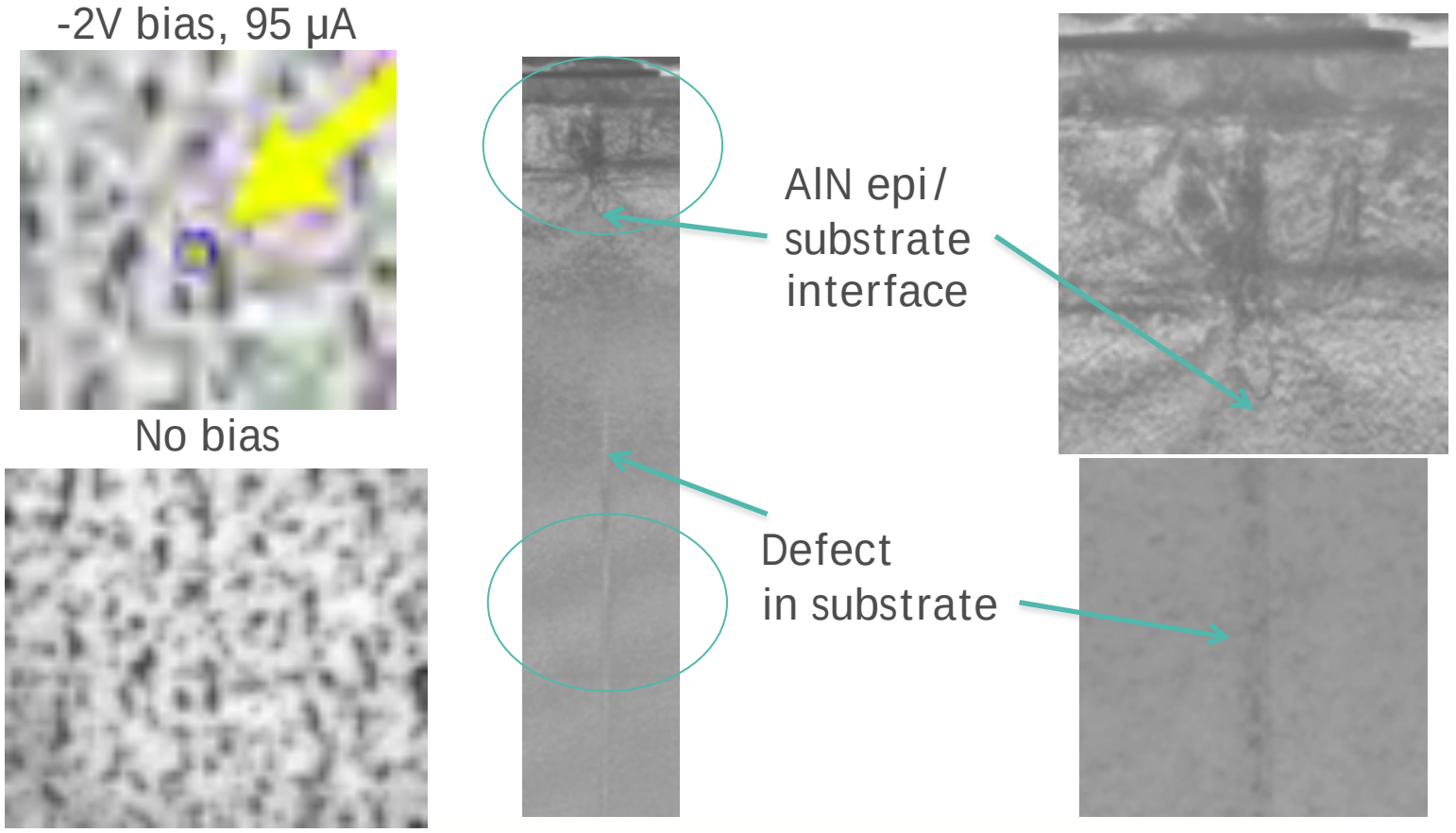
Effect of Current and Temperature on Leakage



- Devices stressed at 100 mA for 48 hrs, then at 300 mA for 1000+ hrs
- Established leakage current failure spec at >1 mA at -5 V
- >35% of leakage failures occur at first test after 300 mA stress (all temperature conditions)
- Leakage failures likely to have a significant current component

Failure Analysis of Accelerated Testing

- Leakage paths identified through emission response imaging at reverse bias.
- Defect in substrate -> locally large defect density in epi layers.

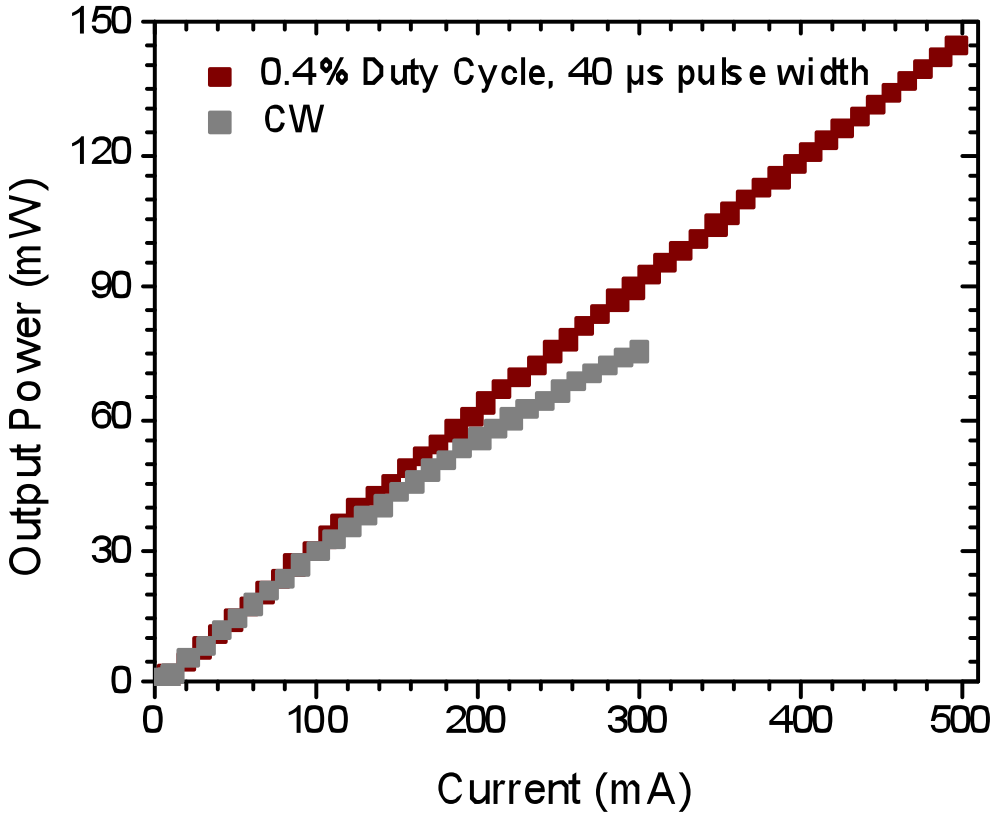


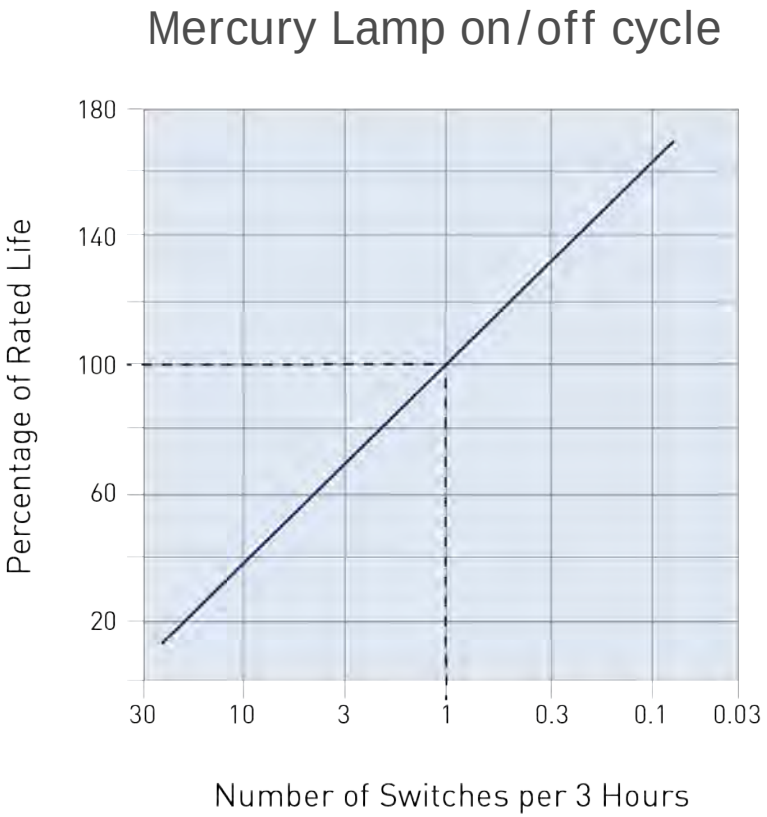
APPLICATIONS

UVC LEDs vs. Mercury Lamps

	Mercury Lamp	UVC LED
Heavy Metals	Mercury (20-200mg)	None
Warm Up Time	1-15 Minutes	Instantaneous
Robustness	Fragile quartz lamp	Shock-resistant
Design Flexibility	Typically straight and long	Small footprint with versatile design options
Voltage	110 - 240V AC	6 - 12V DC
Current	0.5 - 2.0 A	0.02 – 0.3 A
Heat Management	Radiated heat	Back side heat extraction

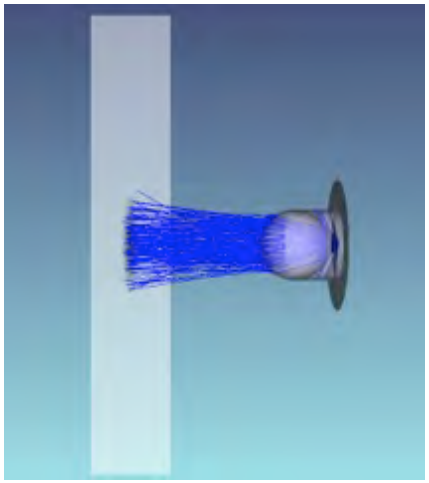
Lifetime Decrease with Cycling (Hg)



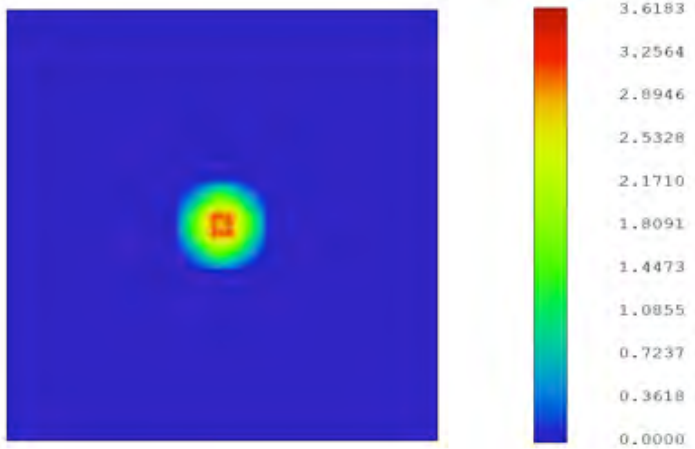


Instant on/off capability of UVC LEDs offers up to 1,000,000 switches per 3 hours

NARROW VERSUS WIDE VIEWING ANGLE

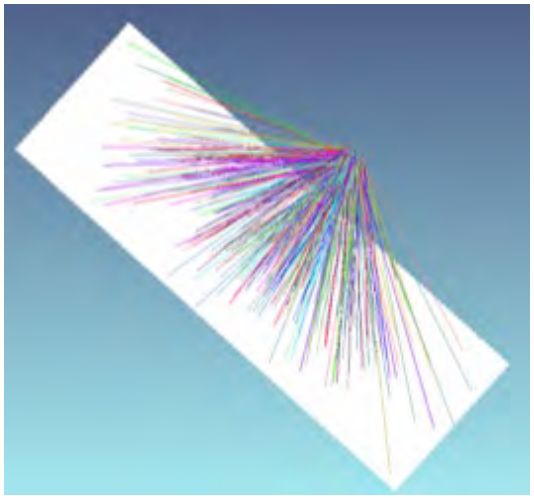


Optan Ball Lens

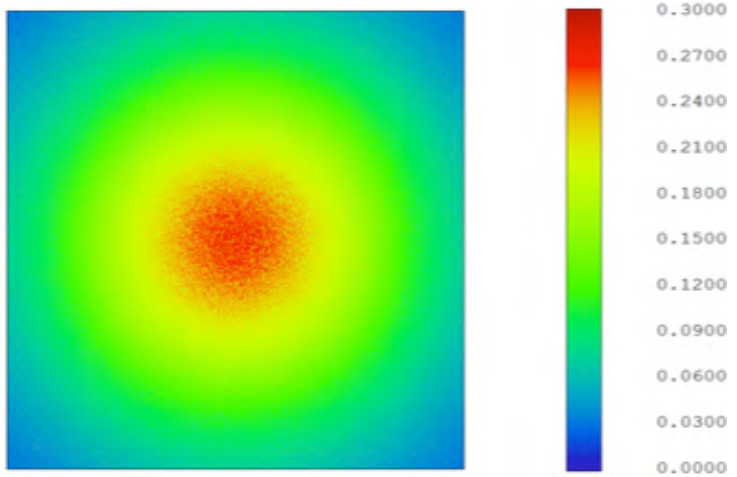


Simulation Result (1mW, 10mm away from detector)

Unit: mW/cm^2



Optan SMD



Simulation Result (2.5mW, 10mm away from detector)

Summary

- First commercial product based on single crystal AlN substrate
- Accelerated lifetime testing studied the effect of increased current and temperature on lifetime.
  - Typical lifetime much greater than 3000 hours
  - Identified junction temperature as the primary acceleration factor over the ranges tested.
  - Further work continues to verify acceleration mechanisms.
- Low defect density of AlN substrates provides improved performance for customers
  - Higher internal efficiency
  - Superior reliability
  - Higher current density

Questions?