SAND2011-3891P

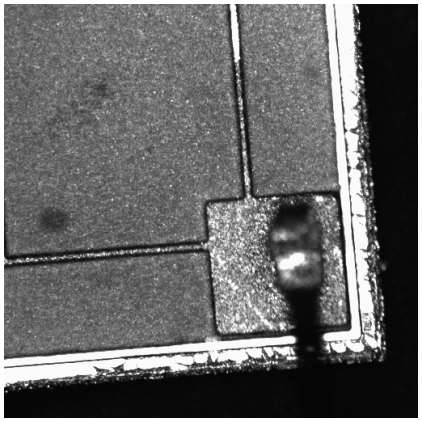
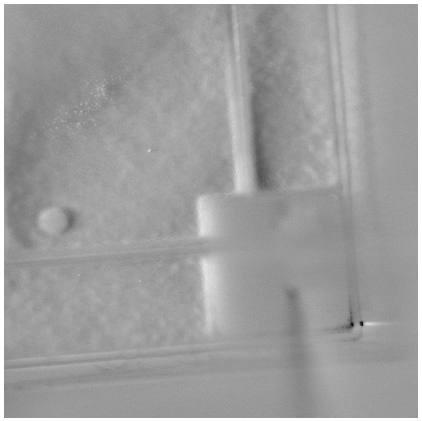
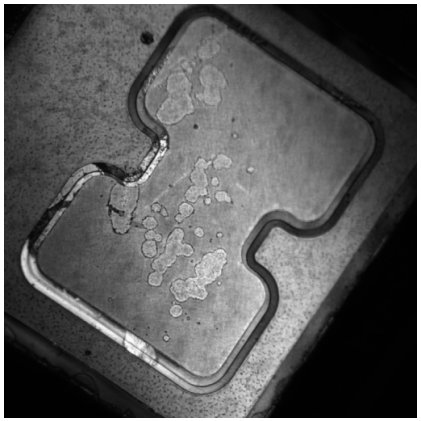
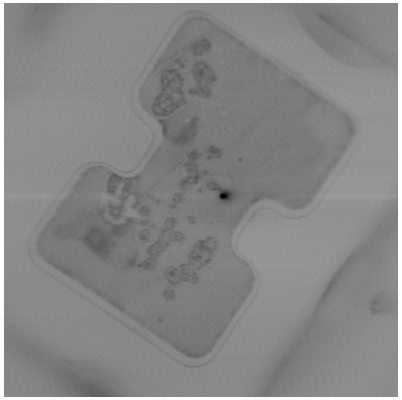
Characterization of Failure Modes in Deep UV and Deep Green LEDs Utilizing Advanced Semiconductor Localization Techniques

Mary A. Miller, Edward I. Cole Jr., and Paiboon Tangyunyong

Sandia National Laboratories is a multi-program laboratory operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin company, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Outline

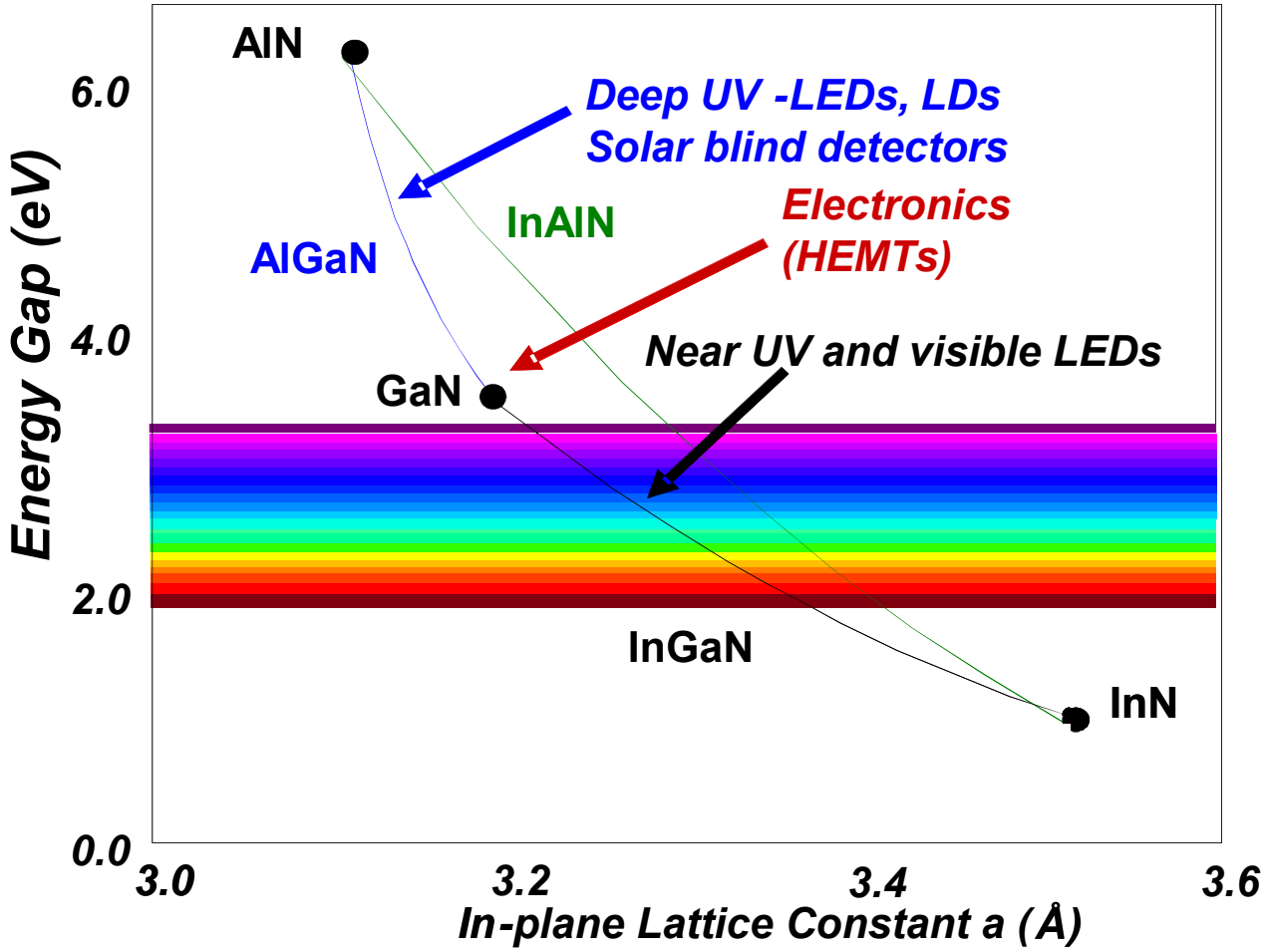
- **Failure Analysis of Commercial LEDs**
- **TIVA/LIVA Imaging of Green and Ultraviolet (UV) LEDs**
  - **Characterization at Time Zero**
  - **Short-term Aging Studies**

Purpose

→ *Describe the use of TIVA and LIVA FA techniques to determine precursors to failure in green and UV LEDs*

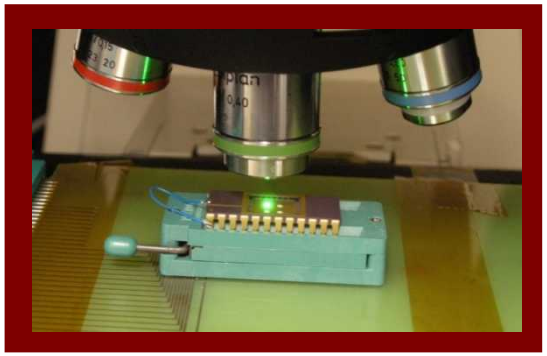
- Nitride-based LEDs could cover the entire visible spectrum and much of the UV.
- Efficiency and reliability drops in the deep UV and deep green.



TIVA and LIVA as FA Techniques for LEDs

Thermally-induced voltage alteration (TIVA) = *laser wavelength is below bandgap energy*

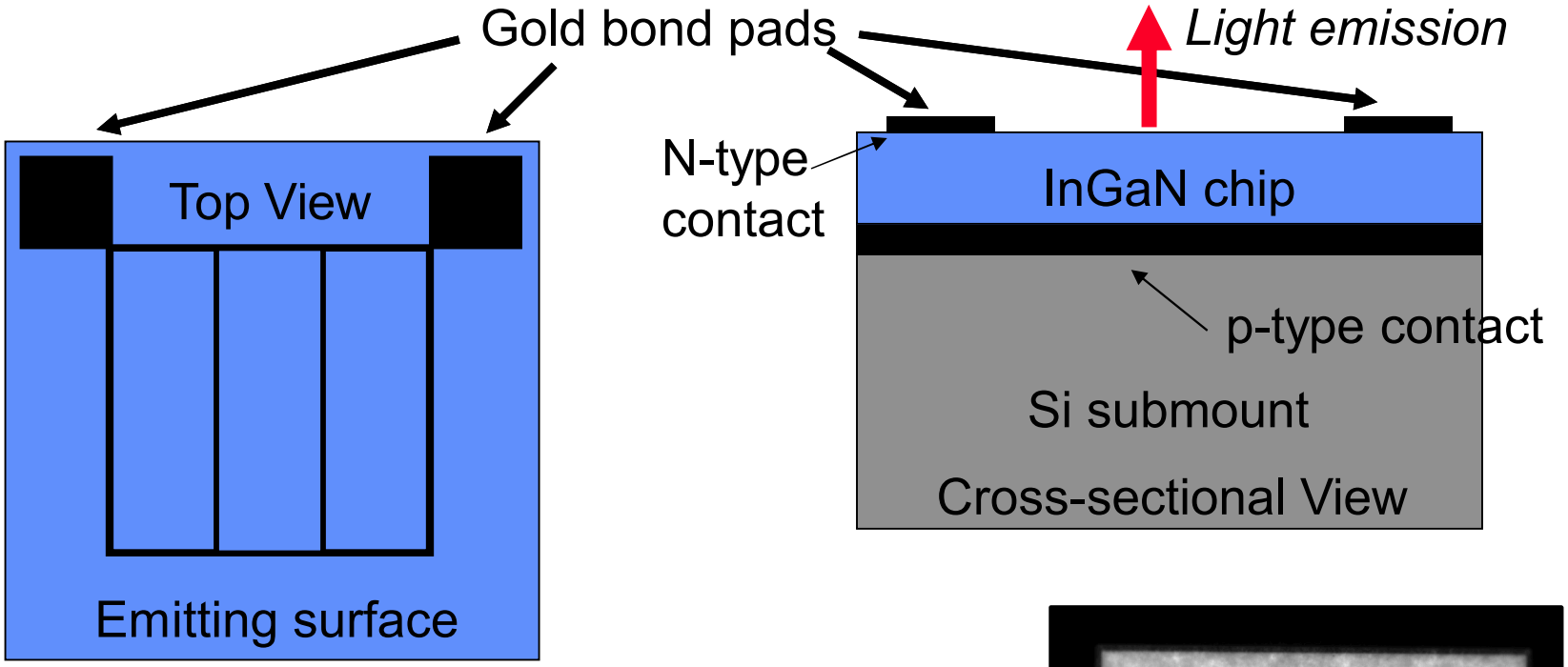
Light-induced voltage alteration (LIVA) = *laser wavelength is above bandgap energy*

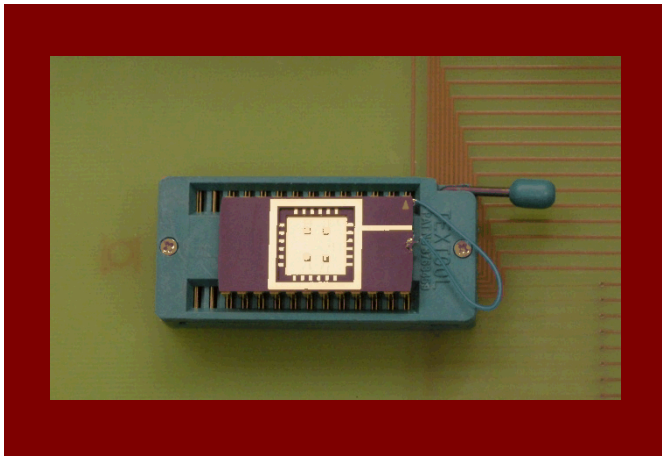


- Uses constant current biasing and voltage measurement with a scanning laser
  - Defect "imaging" by mapping changes in power demand by laser position
- Apply to green (525-535nm) and UV (270-280nm) LEDs
- Laser approaches do not require deprocessing of III-nitride devices

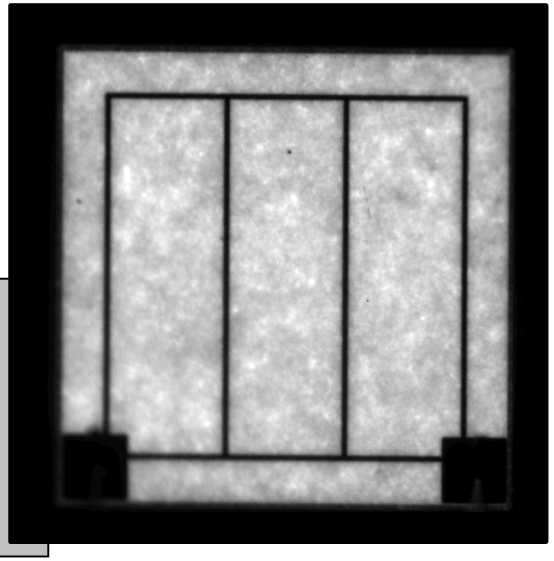
→ Can FA techniques localize electrically active defects in nitride-based materials where there are large background defect densities?

Green Light Emitting Diodes: 525-535nm



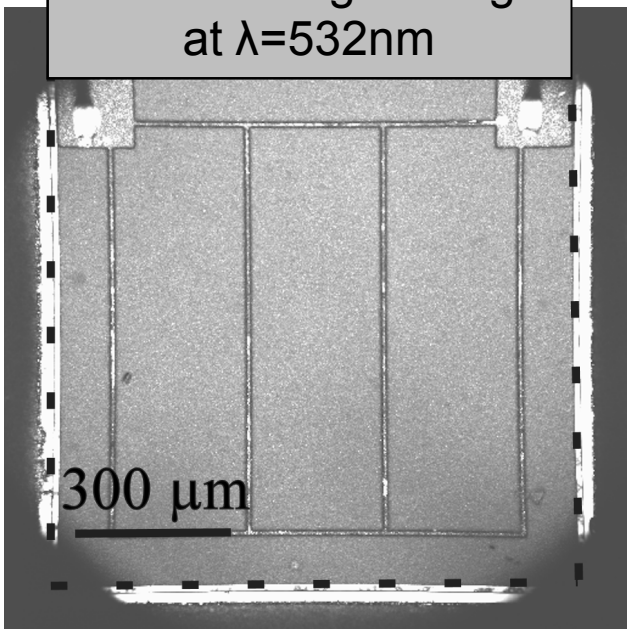


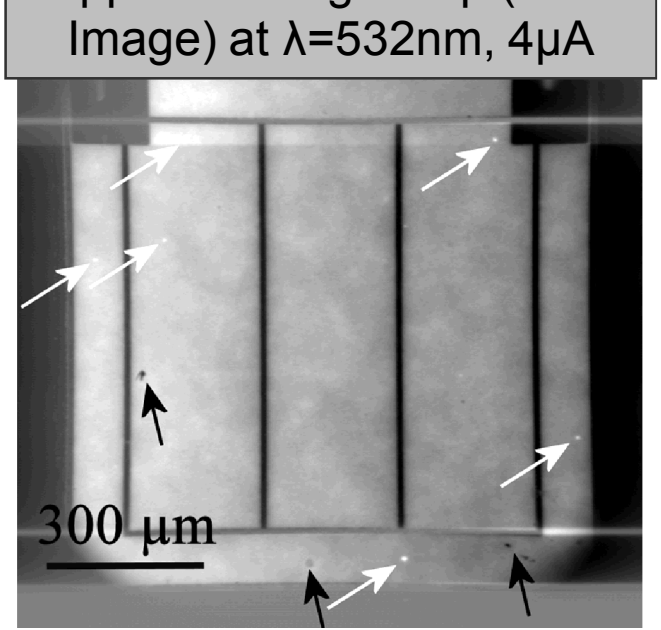
Light Emission image showing the emitting area of the chip

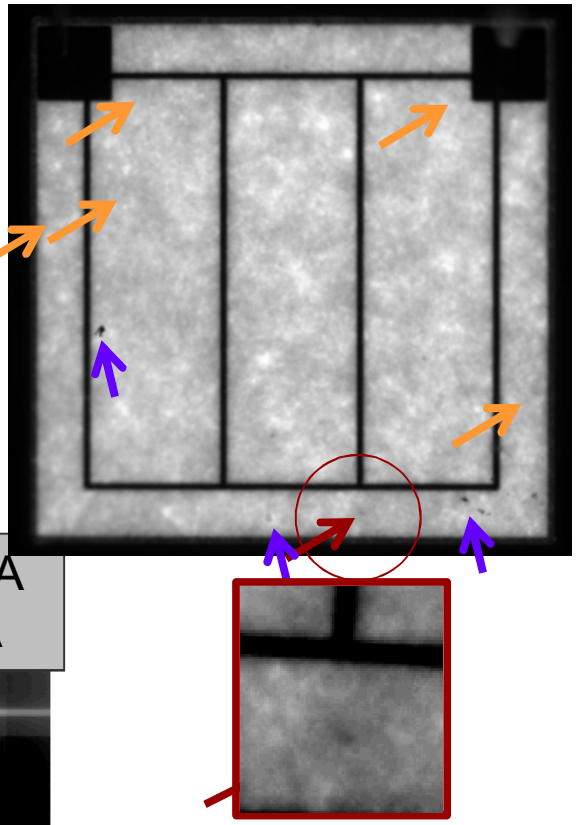


TIVA/LIVA Imaging of Green LEDs

- ~5-20 bright defect spots observed per device
- Intensity was defect and bias dependent
- No bright defect signal from 1340 or 1064nm lasers → *LIVA signal only, indicates an electron-hole (e-h) pair recombination site*
- Only one matching spot in the LE image

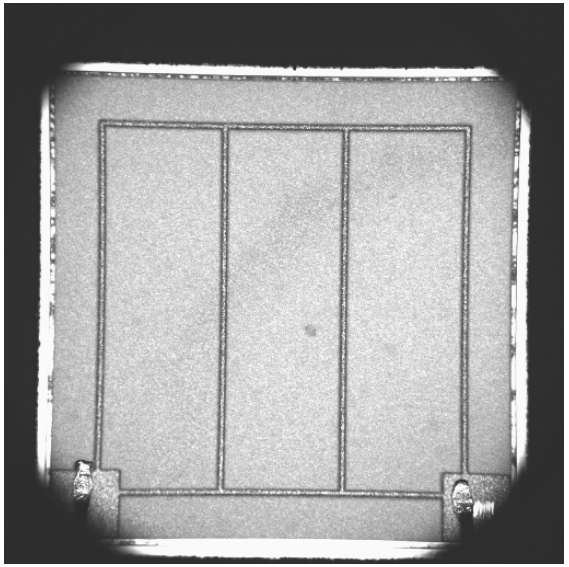






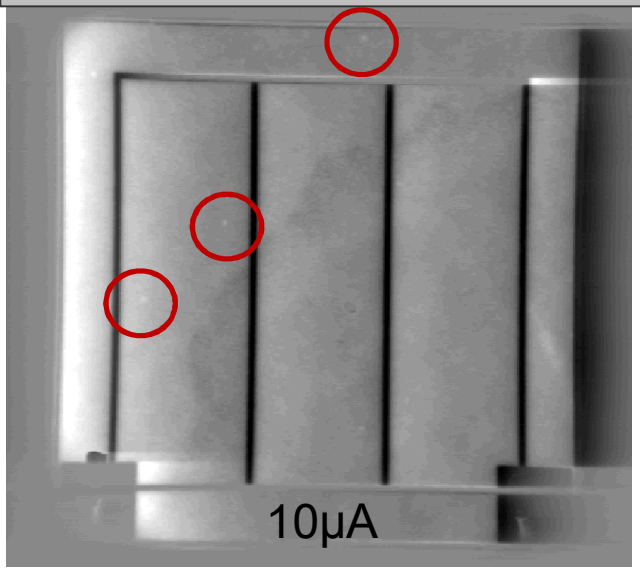
TIVA/LIVA Imaging of Green LEDs

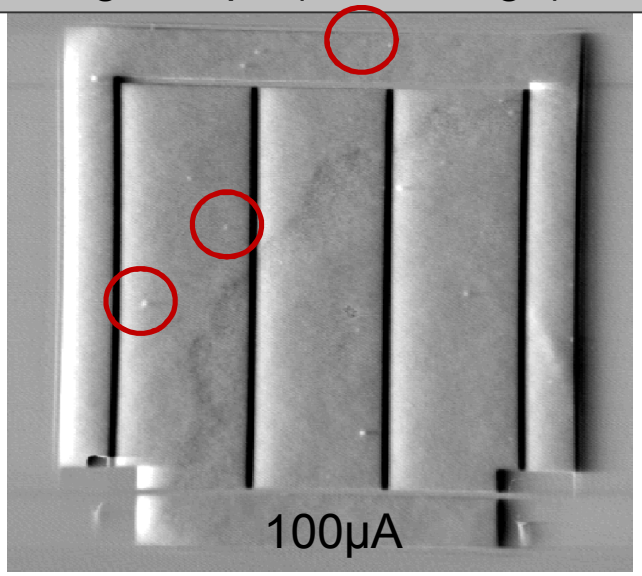
Reflected Light Image at λ=532nm

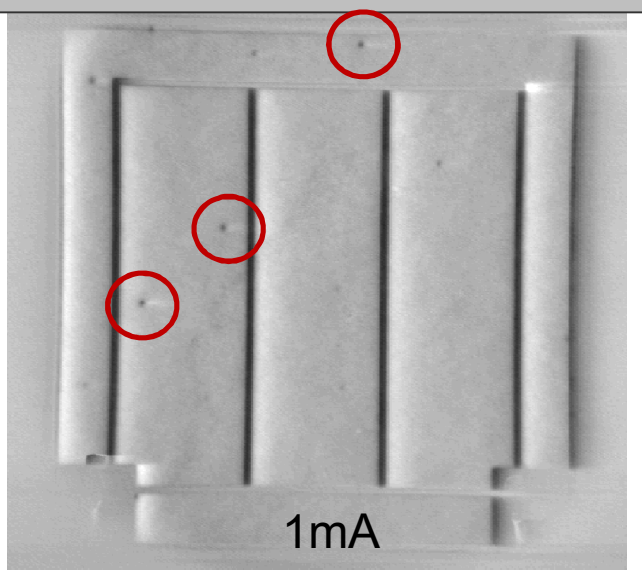


- The bright defect spots are bias dependent—the most show up near 100μA
- Some of the defects switch polarity at higher currents

Applied Voltage Maps (LIVA Image) at λ=532nm



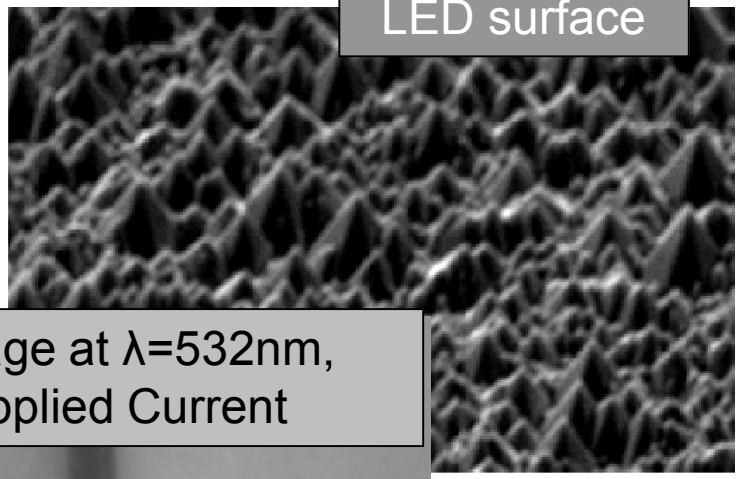




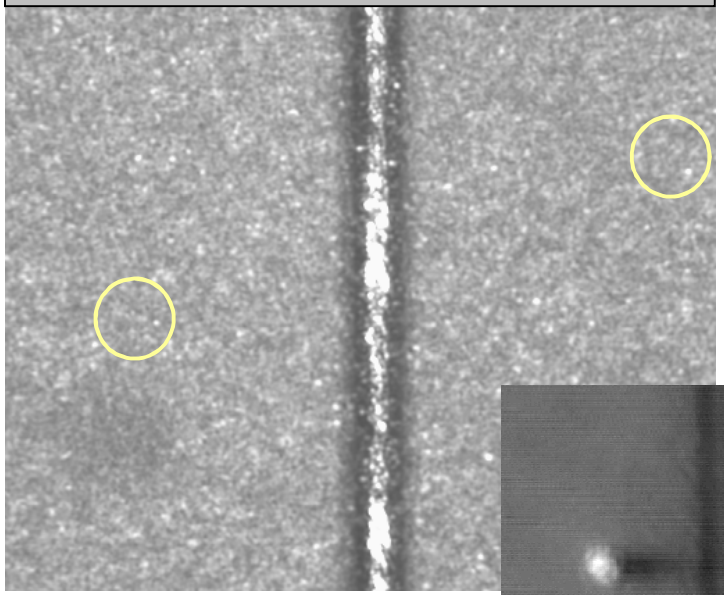
TIVA/LIVA Imaging of Green LEDs

- Defects were not matched to physical features
  - *masked by surface roughness*
  - *within the thickness of the chip*
  - *too small to be optically resolved*

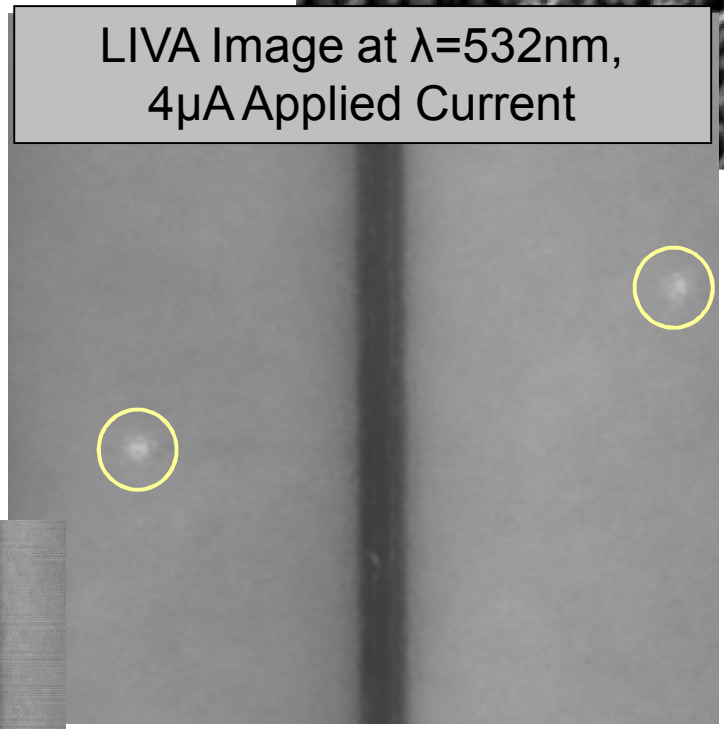
SEM image of LED surface



Reflected Light Image at λ=532nm

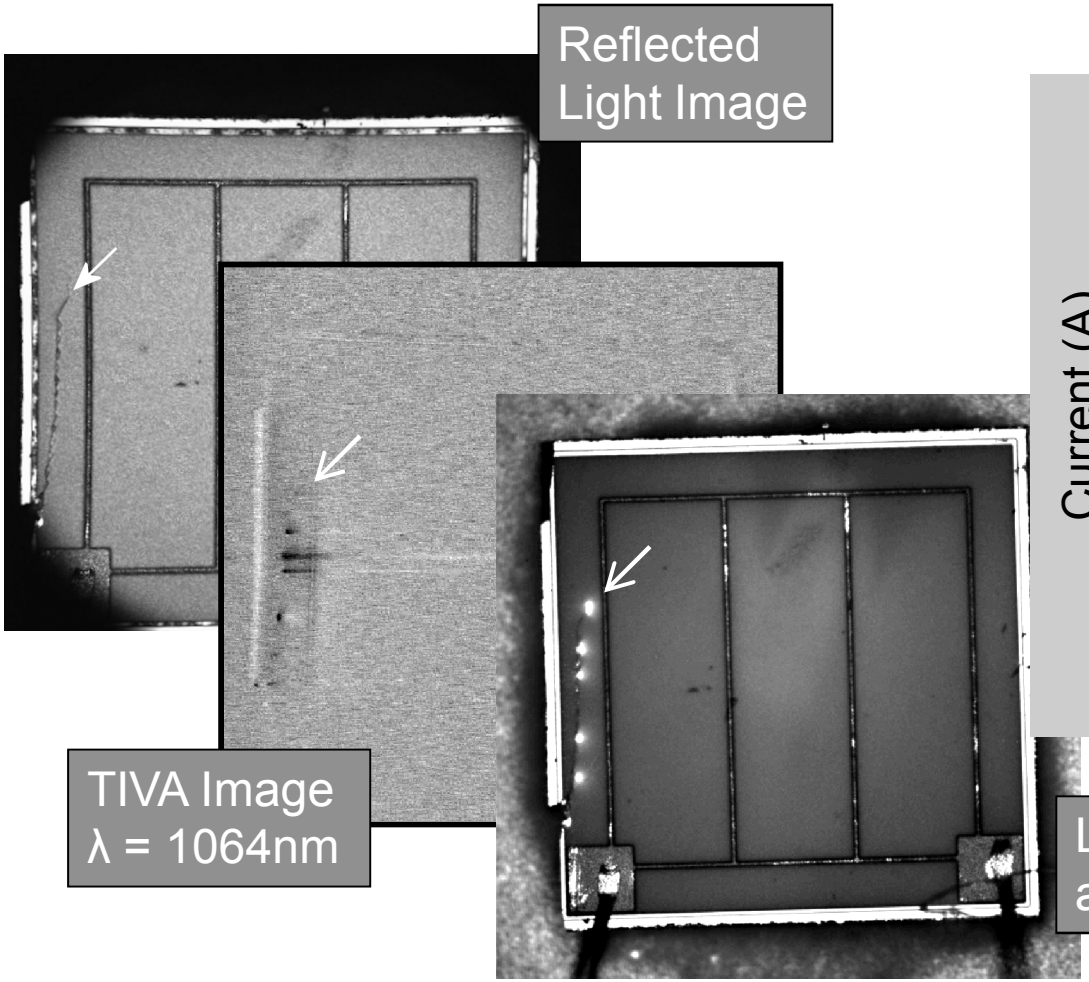


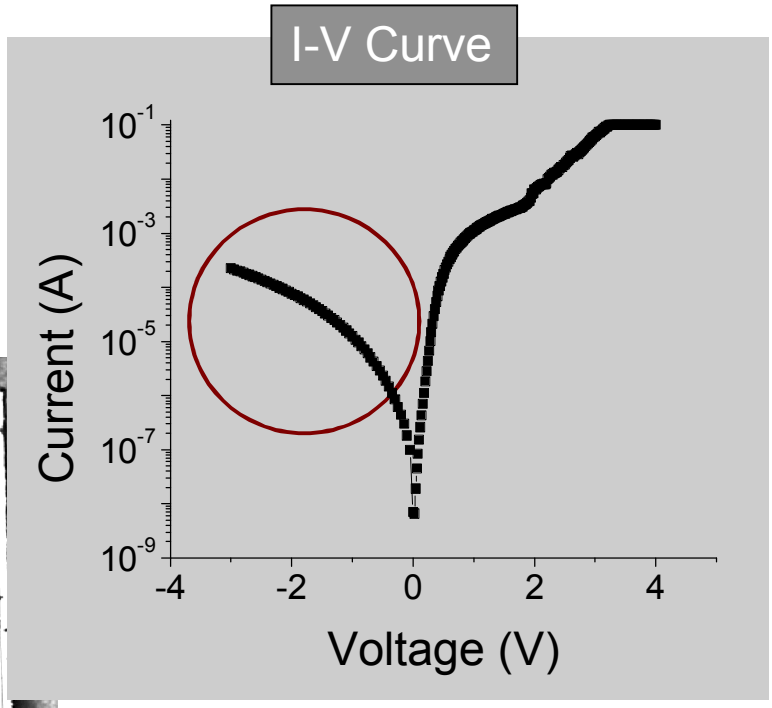
LIVA Image at λ=532nm, 4μA Applied Current



TIVA/LIVA Imaging of Green LEDs

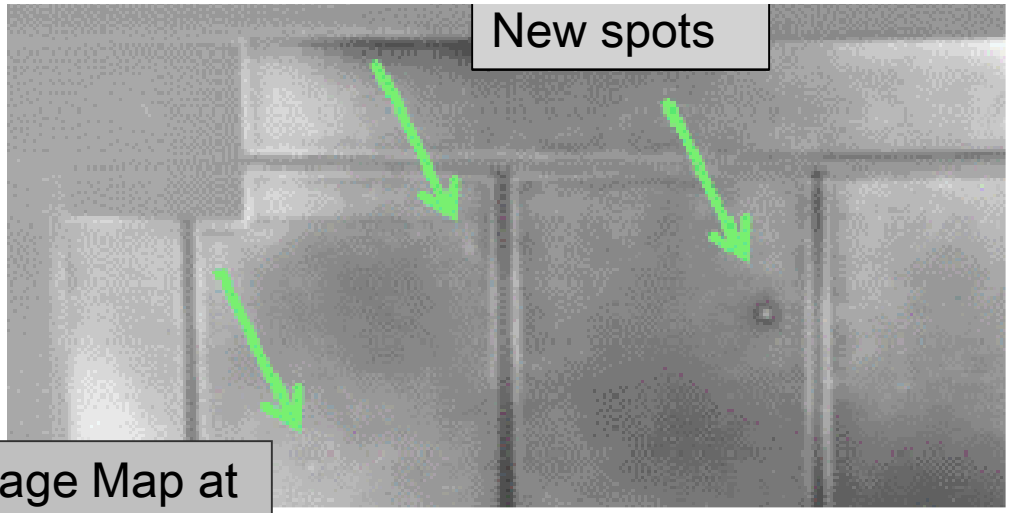
- 5 of the 24 LEDs had strong leakage currents
- Each LED had strong defect signals at 1064nm and 1340nm (TIVA signals)
- LE and IV curves also gave indications of leakage paths





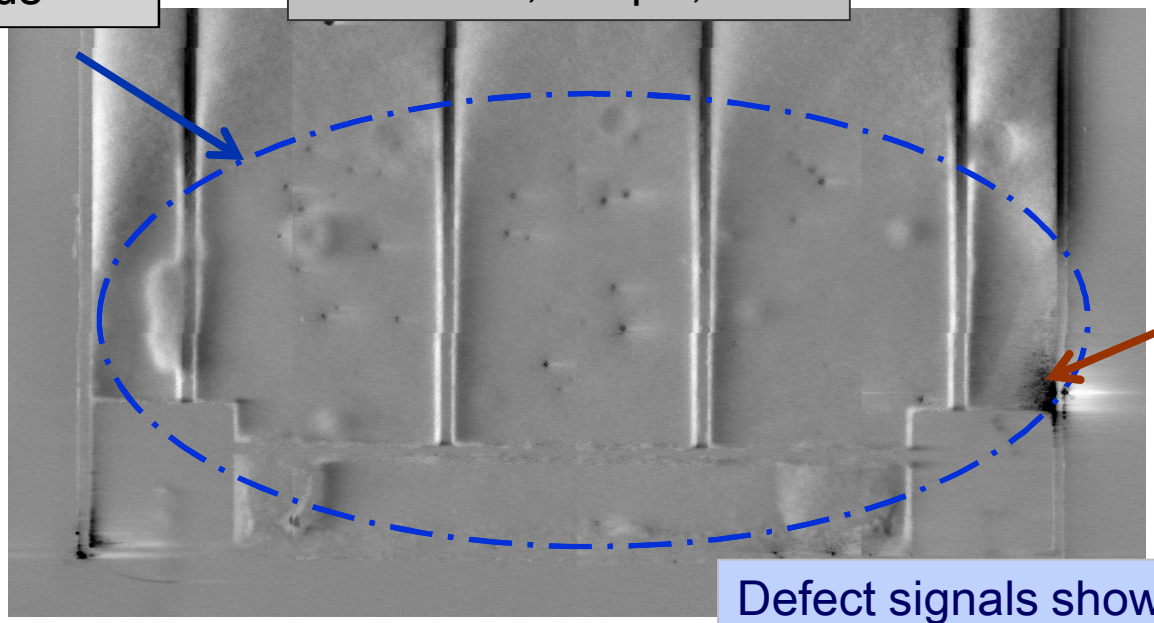
Stress-Induced Changes in Green LEDs

1. No change
2. Catastrophic shorts
3. Haze
4. Water spots
5. New spots



Haze near the bondpads

Applied Voltage Map at λ=532nm, 100μA, 5hrs



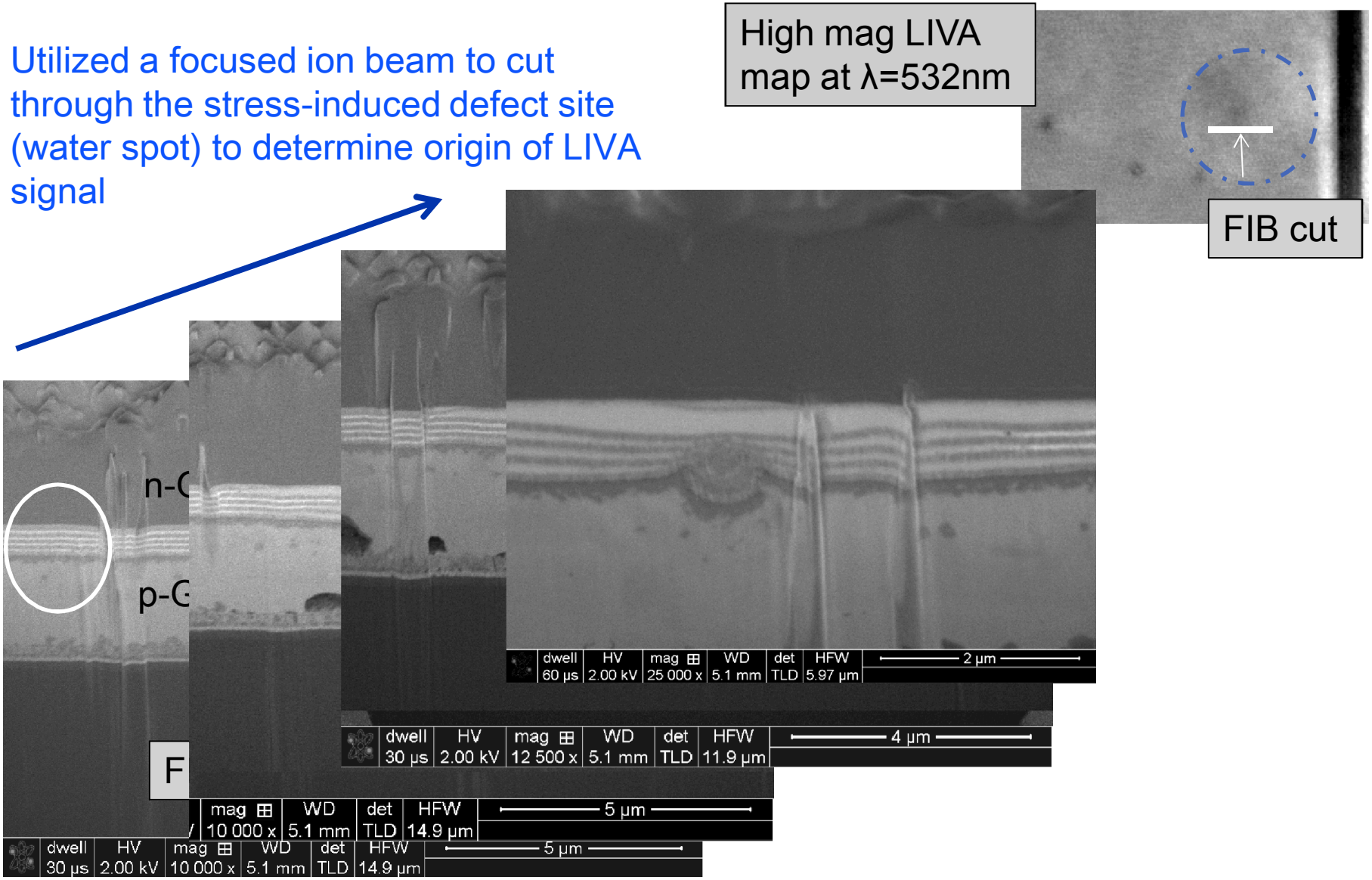
Shorting path—observed under all laser wavelengths

Defect signals shown here are stress-activated; they were not visible at time zero

Stress-Induced Defects in Green LEDs—FIB Cross-section of Defect Site

Utilized a focused ion beam to cut through the stress-induced defect site (water spot) to determine origin of LIVA signal

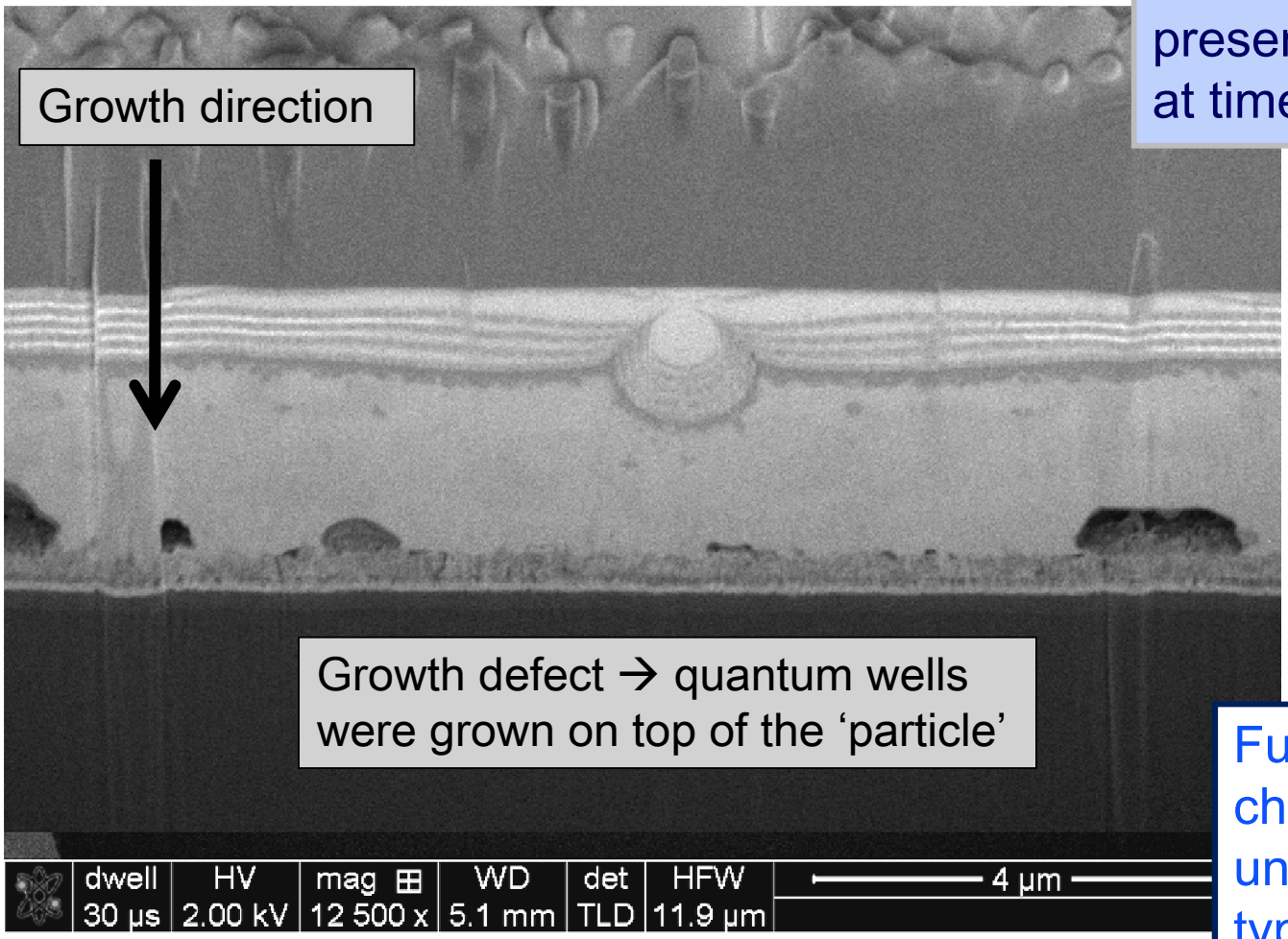
High mag LIVA map at λ=532nm



Cross-section of Stress-Induced Defect Site in Green LEDs

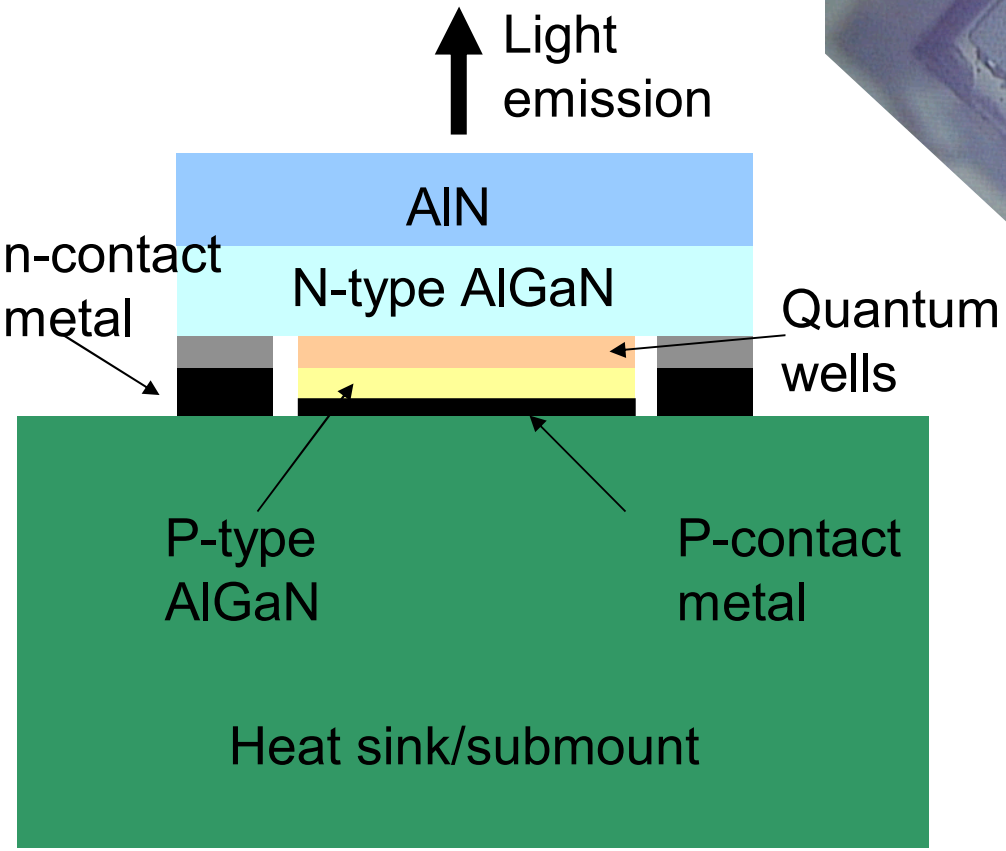
Growth defect found in commercial part → could present a reliability concern as a potential shorting path

-IVA signal was not present for this defect at time zero

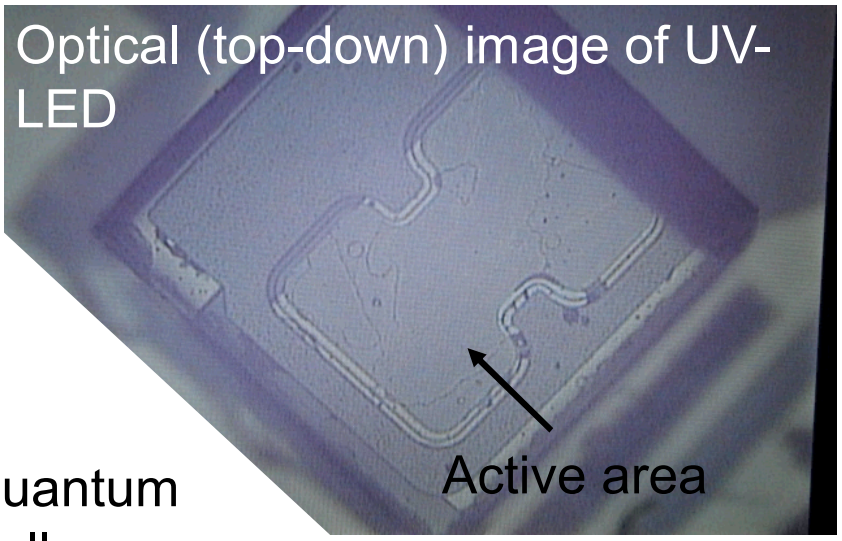


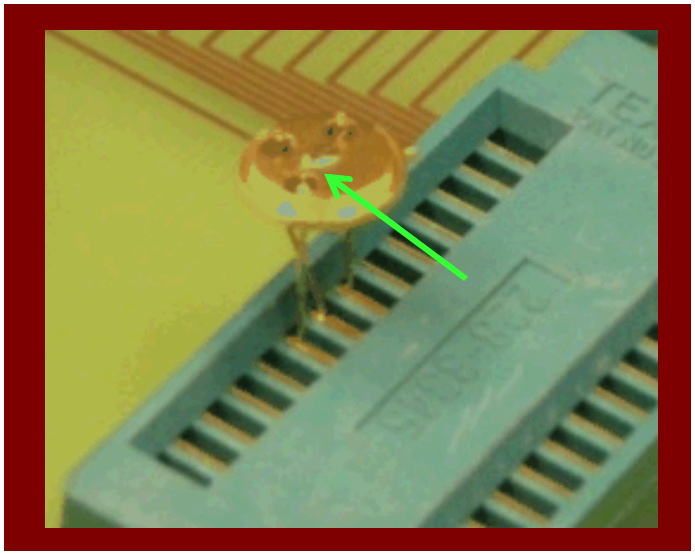
Further FIB/TEM characterization is underway for other types of defects

UV Light Emitting Diodes: 270-280nm



Cross-sectional view of UV LED

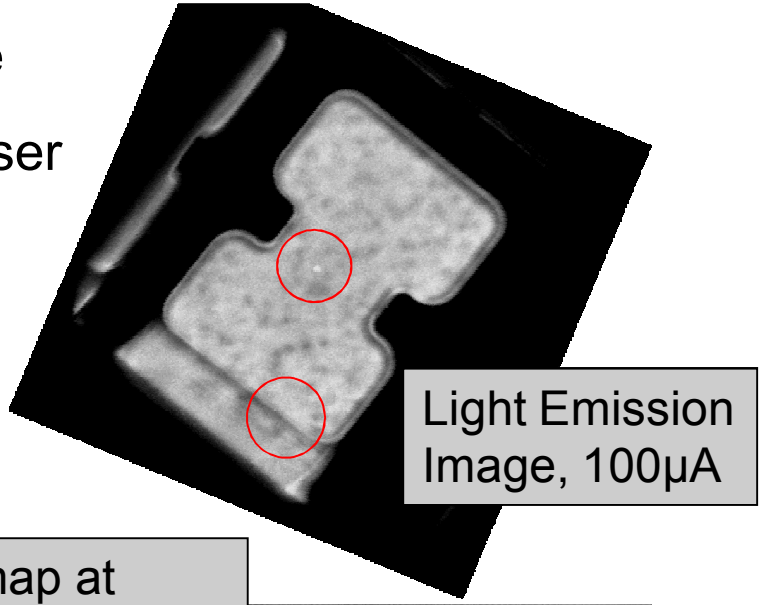




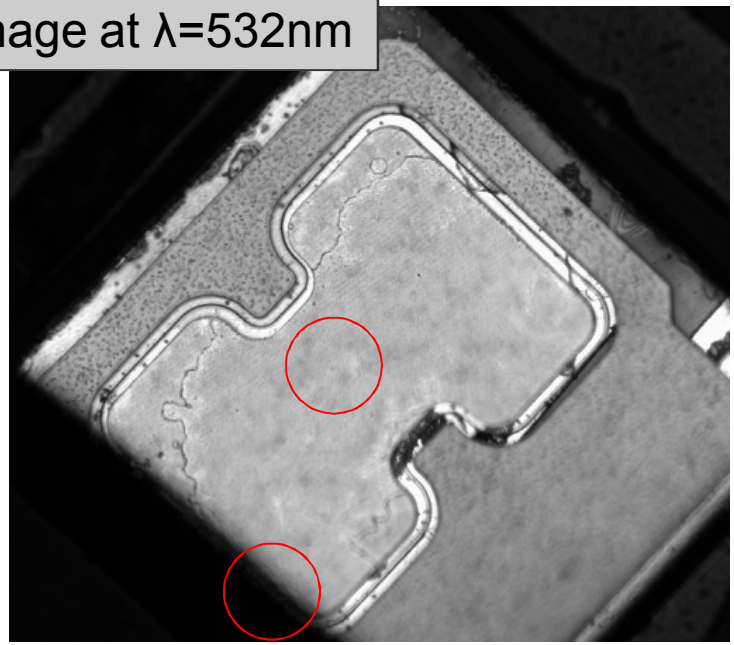
LED chip mounted to a TO-39 can without the lens

TIVA/LIVA Imaging of UV LEDs

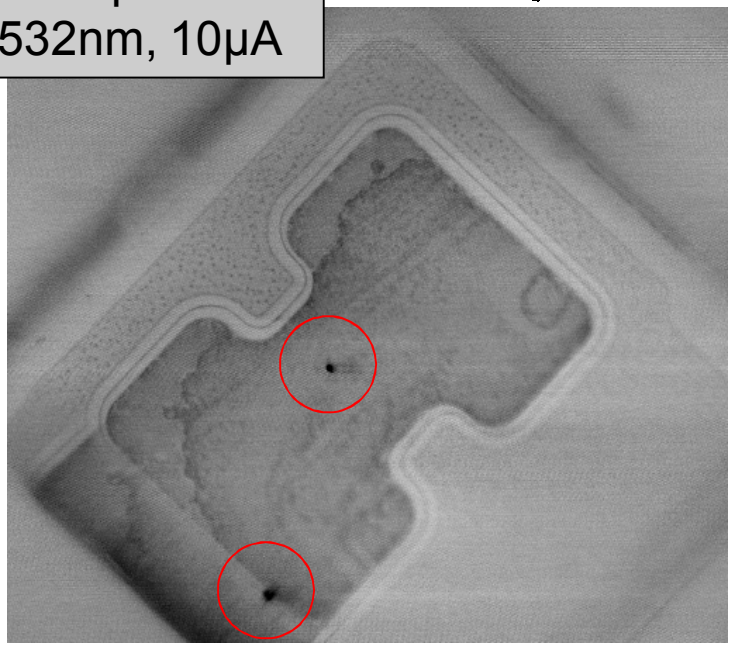
- Dark defect signals have a turn on voltage
- Signals always present with the 532nm laser
- Mixed response to 1064nm and 1340nm lasers → mixed TIVA/LIVA signals
- Light emission shows only some of the -IVA sites



Reflected Light Image at λ=532nm

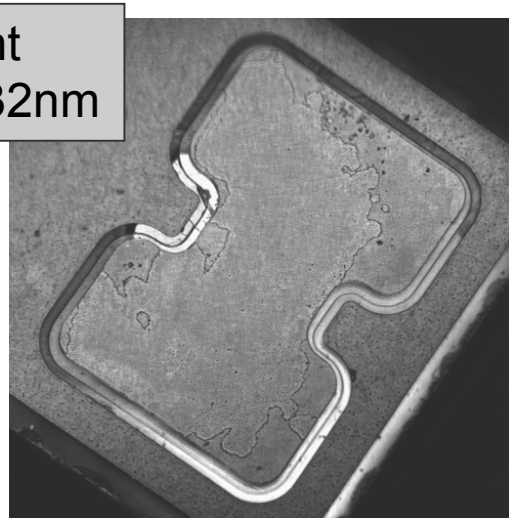


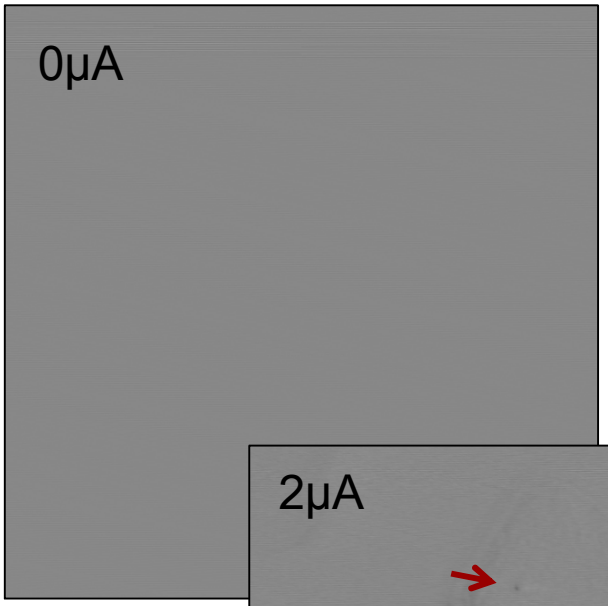
-IVA map at λ=532nm, 10µA

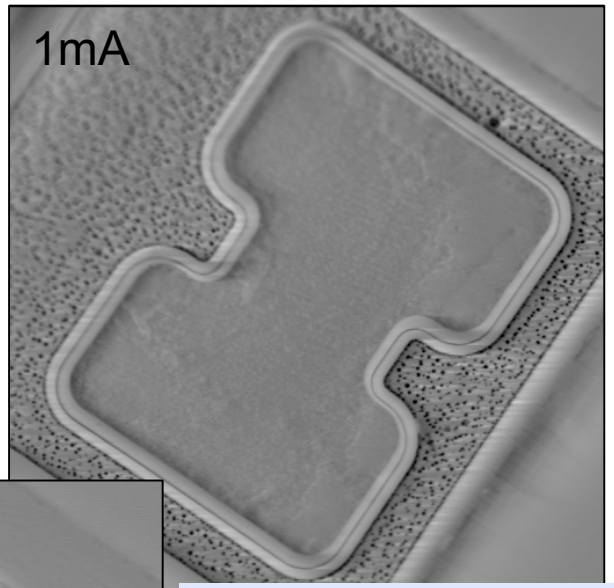


TIVA/LIVA Imaging of UV LEDs

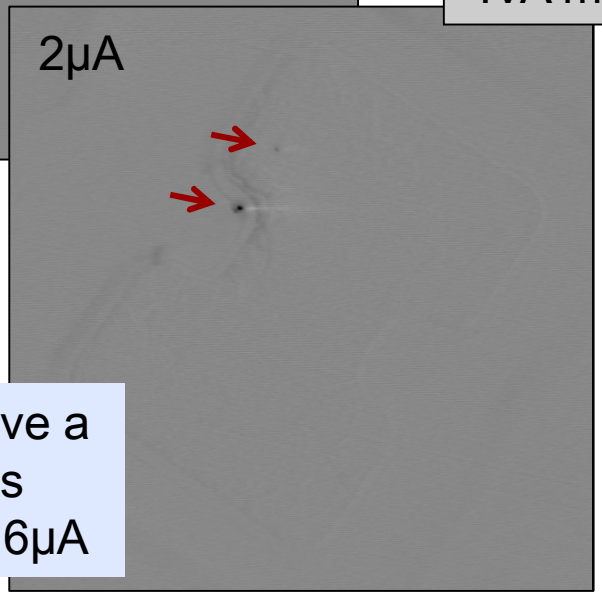
Reflected Light Image at λ=532nm

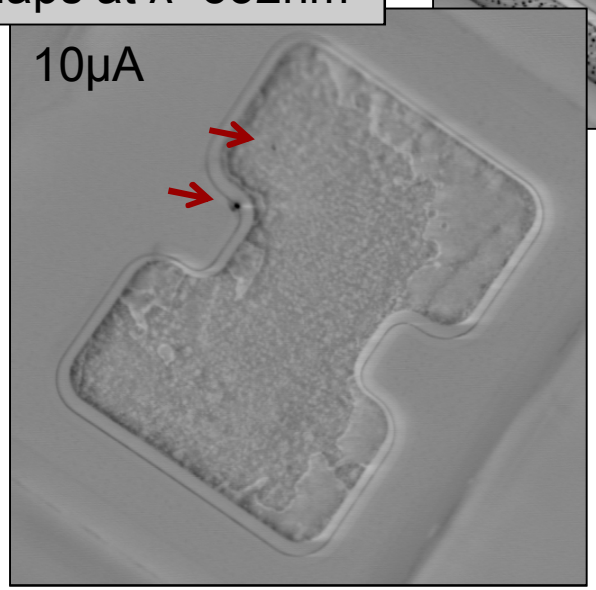






-IVA maps at λ=532nm



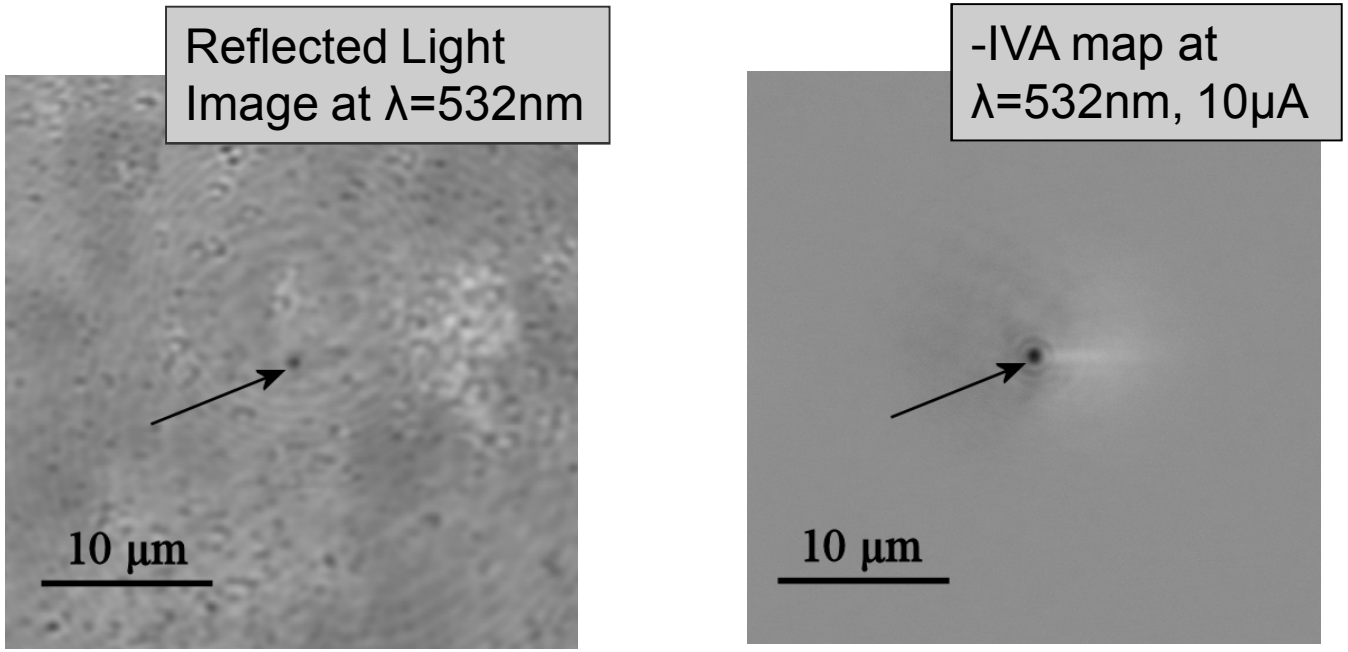


Defects have a turn-on bias near 0.4-0.6μA

Defects are lost in the background signal at higher currents (typically >1mA)

TIVA/LIVA Imaging of UV LEDs

- All spots had physical defects at the origin of the signal
- All of the tested UV LEDs had 0-4 defect spots



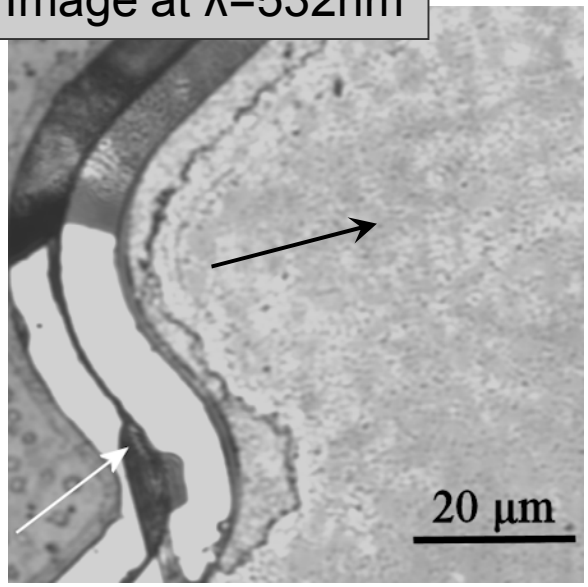
TIVA/LIVA FA techniques identified electrically active defects among a large number of optically similar sites

Aging of UV LEDs

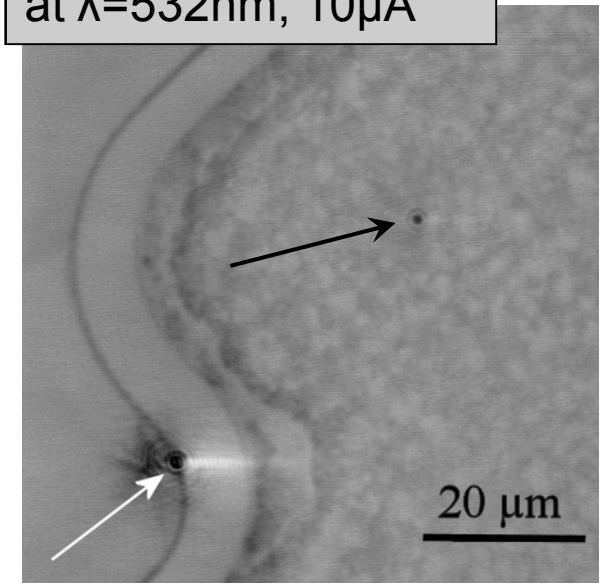
After 19 hours of aging at 30mA (~100Acm^{-2}), changes were detected in the –IVA map

- Bright signal appears at negative bias
- Bright signal has a turn on voltage
- Not all defect spots changed with time

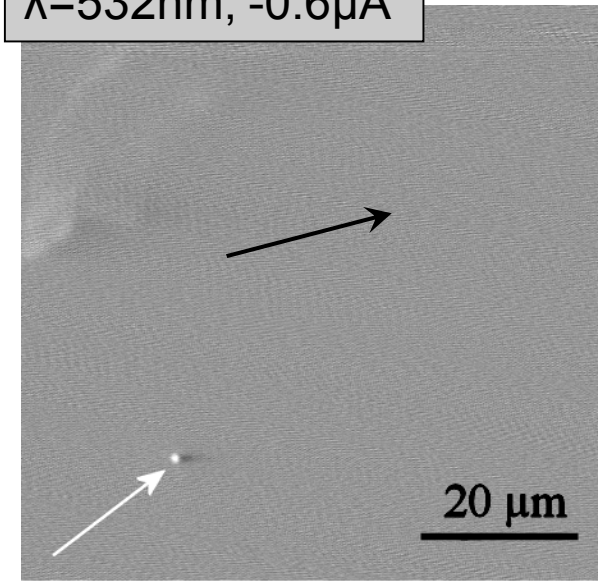
Reflected Light Image at λ=532nm



Applied Voltage Map at λ=532nm, 10µA



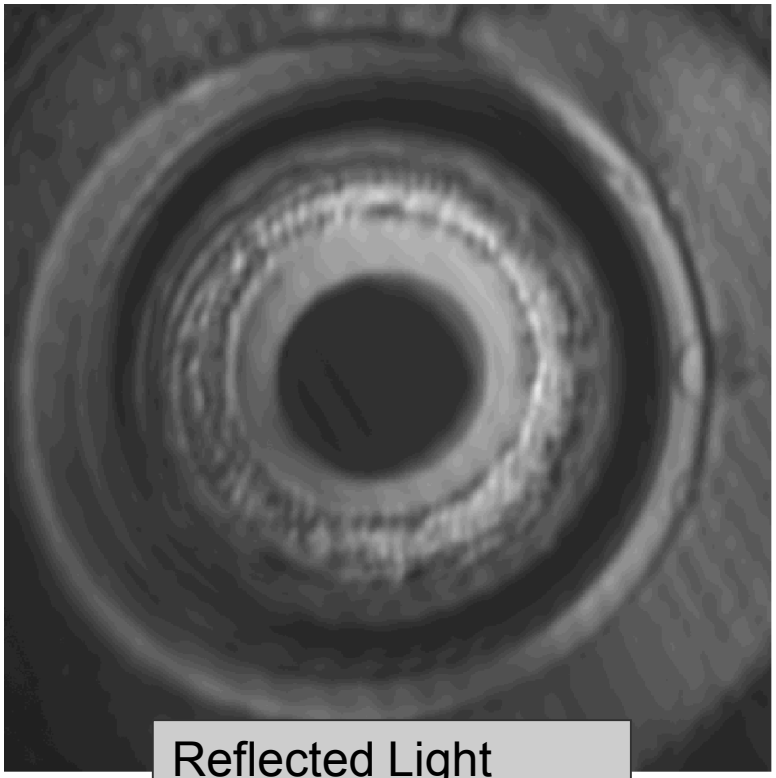
-IVA Map at λ=532nm, -0.6µA



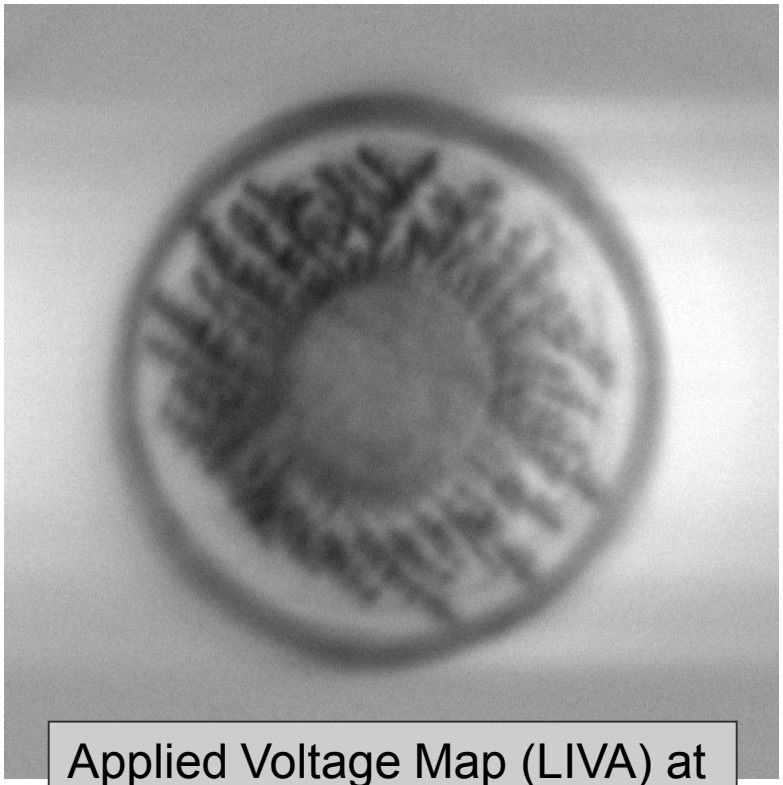
Suggests different types of defects are present in UV LEDs

Vertical Cavity Surface-Emitting Lasers (VCSELs)

- TIVA/LIVA was successfully applied to VCSEL technology
- Dislocation networks were localized in failed parts



Reflected Light Image at λ=1064nm



Applied Voltage Map (LIVA) at λ=1064nm, zero applied bias

Summary

- **TIVA and LIVA FA techniques were successfully used to localize electrically active defects in nitride-based COTS LEDs**
- **FA techniques were able to measure subtle differences in aged devices**