SWISS PHOTONICS

Visible Superluminescent LEDs for Smart Lighting

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EXALOS
The bright light source company

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Outline

Introduction

- **What are SLEDs ?**
- **SLEDs for Projection Systems**
- **Speckle Reduction using SLEDs**

Visible SLED Devices

- **Red SLEDs in GaAs**
- **Blue SLEDs in GaN**
- **GaN device design & performance**
- **Towards Green SLEDs**
- **SLED reliability**

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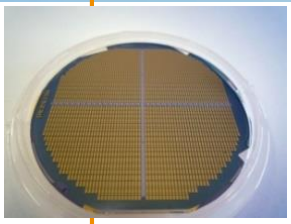
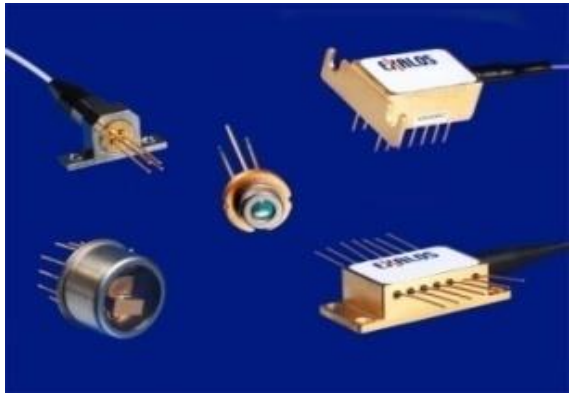
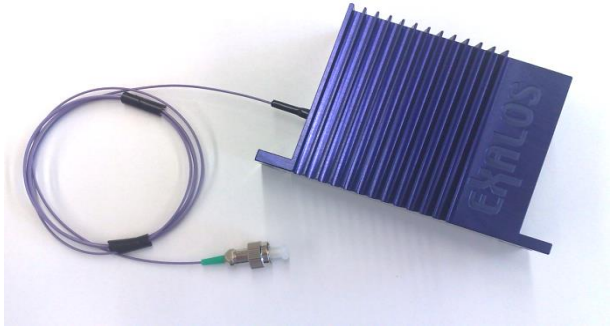
About EXALOS





- EXALOS founded 2003
- Headquarter in Zurich, Switzerland
- Sales offices in US & China



- **Superluminescent Diodes (SLEDs)**
- Broadband Ligth Sources
- Fast Tunable Lasers (Swept Lasers)
- GaN-based SLED, microLED and Laser Diodes

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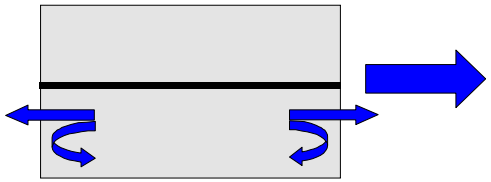
What are SLEDs?

SLEDs: a bridge between LDs and LEDs

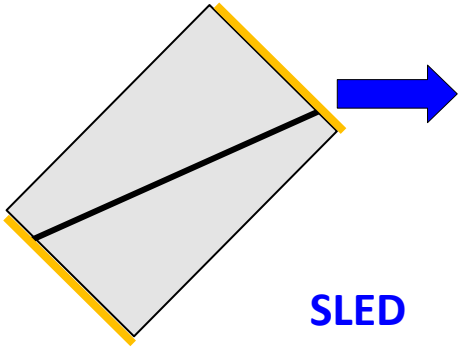
Stimulated Emission (narrowband, directional)	ASE (broadband, directional)	Spontaneous Emission (broadband, not directional)

Laser cavity, gain, feedback



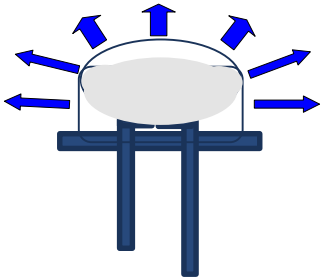
FP LD

Single-pass gain in waveguide

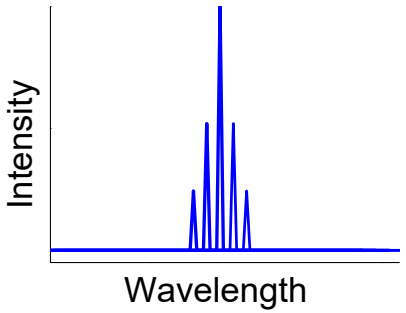


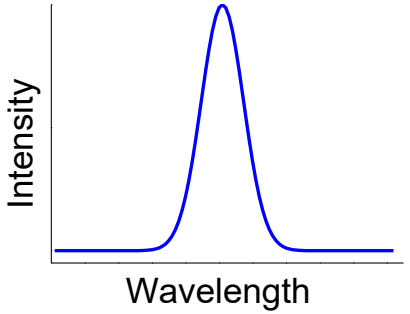
SLED

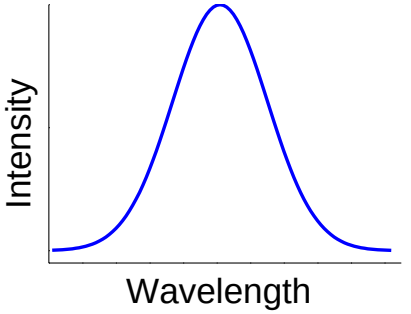
No cavity, No gain No feedback



LED







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What are SLEDs?

An SLED can be considered a:

- Spatially coherent laser diode with broadband output
- Temporally incoherent, speckle-free laser diode
- LED with a beam-like output and good coupling to fibers

	LD	SLED	LED
Principle of Light Generation	Stimulated Emission	Amplified Spontaneous Emission	Spontaneous Emission
Optical Spectrum	Narrowband or multiple Fabry-Perot modes	Broadband	Broadband
Total optical output power	High	High-Medium	Medium
Optical power density	High	Medium-High	Low
Optical waveguide	Yes	Yes	No
Light Emittance	Divergence-limited	Divergence-limited	All directions
Spatial coherence	High	High	Low
Coupling into single-mode fibers	Efficient	Efficient	Poor
Temporal coherence	High	Low	Low
Generation of speckle noise	High	Low	Low

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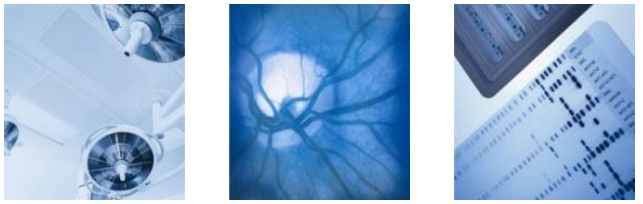
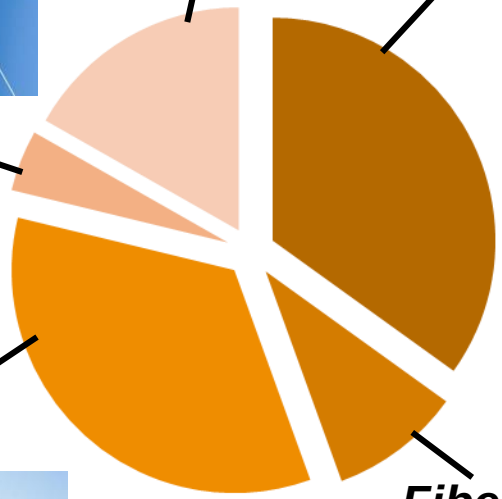
Existing SLED Applications

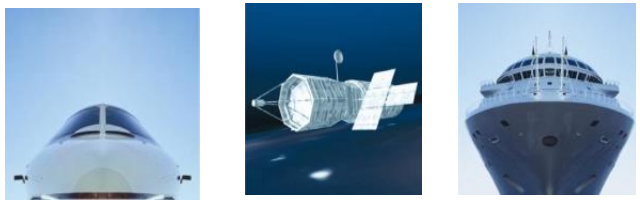
Other applications (Metrology, Machine Vision & Illumination Systems)

Fiber Optics Sensors (FOS)
Strain, pressure, current

Medical Applications (OCT)
Corneal and retinal diagnostics







Fiber Optic Test Equipment (FOT)
Optical channel monitors

Fiber Optics Gyroscopes (FOG)
Navigation system (air, space, sea, land)

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SLEDs for Projection Systems

Broadband Spectrum = low (temporal) coherence

(from microvision.com)

LEDs:	No speckle ☺ Need focusing ☹
LDs:	Speckle ☹ No focusing ☺
SLEDs:	No speckle ☺ No focusing ☺

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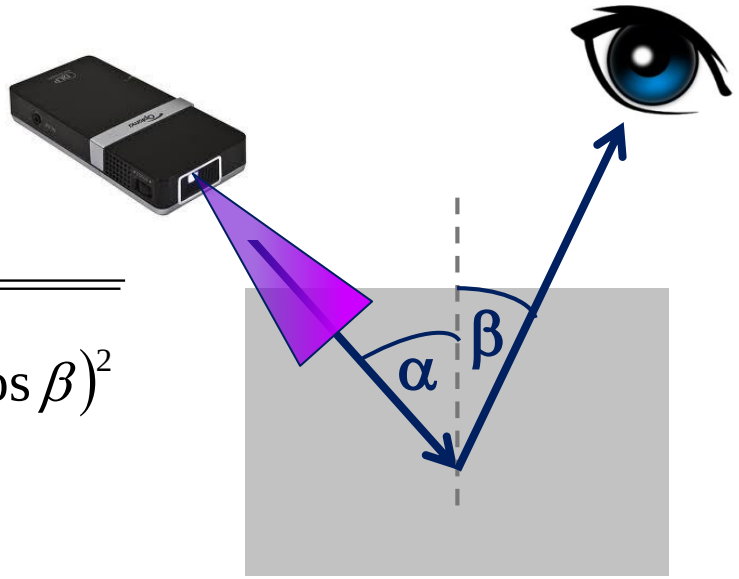
Speckle Contrast in Projection Systems

- Speckle contrast in projection systems with light sources of partial temporal coherence is given by:

$$C = \frac{1}{\sqrt[4]{1 + 2\pi^2 \left(\frac{\Delta\lambda}{\lambda_m}\right)^2 \left(\frac{\sigma_h}{\lambda_m}\right)^2 \cdot (\cos\alpha + \cos\beta)^2}}$$



Optical bandwidth of light source

Surface height standard deviation

Mean wavelength

Speckle Contrast Reduction

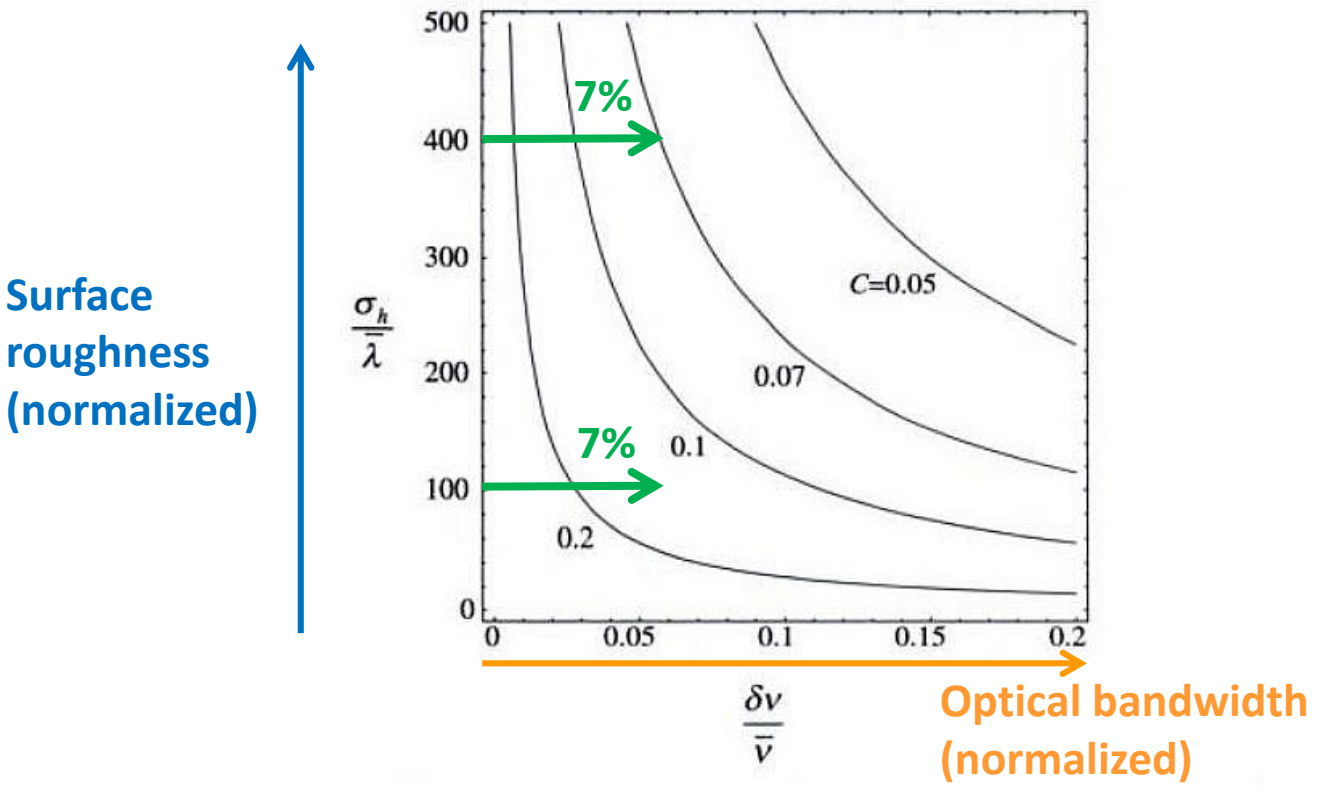


Figure 5.18 Contours of constant contrast C as a function of fractional bandwidth $\delta\nu/\bar{\nu}$ and surface height standard deviation normalized by the mean wavelength, $\sigma_h/\bar{\lambda}$. Normal incidence and observation angles are assumed.

- Typical fractional bandwidth of SLEDs = 3-10%
- Reduction of speckle contrast by using SLEDs depends on surface roughness …

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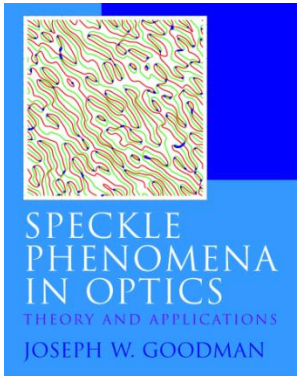

AR Projection Systems

- Augmented reality (AR) glasses use a projection screen and are therefore also sensitive to speckle noise generation !

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VR Imaging Systems

- Most of today's virtual reality (VR) glasses use a minituarized active dual-eye display without projection and are therefore not sensitive to speckle noise !

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AR Head-Up Display (HUD) Systems

- Augmented-reality HUD system display information over driver's or pilot's line of sight and use the windshield as a projection plane → sensitive against speckle noise

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- SLEDs for Picoprojectors
- Speckle Reduction

Visible SLED Devices

- **Red SLEDs in GaAs**
- **Blue SLEDs in GaN**
- **GaN device design & performance**
- **Towards Green SLEDs**
- **Visible SLEDs reliability**

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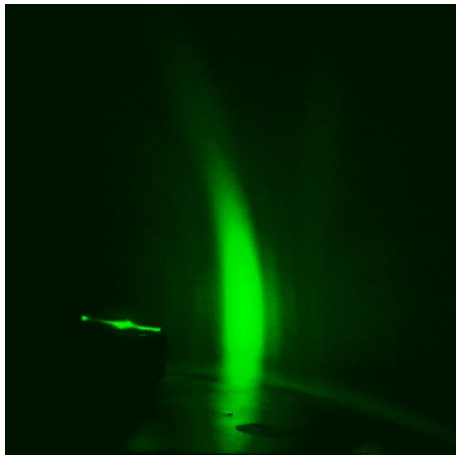
EXALOS‘ Material Systems

1995 1997 1999 2001 2003 2005 2007 2009 2011 2013

InP 1100-1700nm

GaAs 630-1050nm

GaN 400-550nm



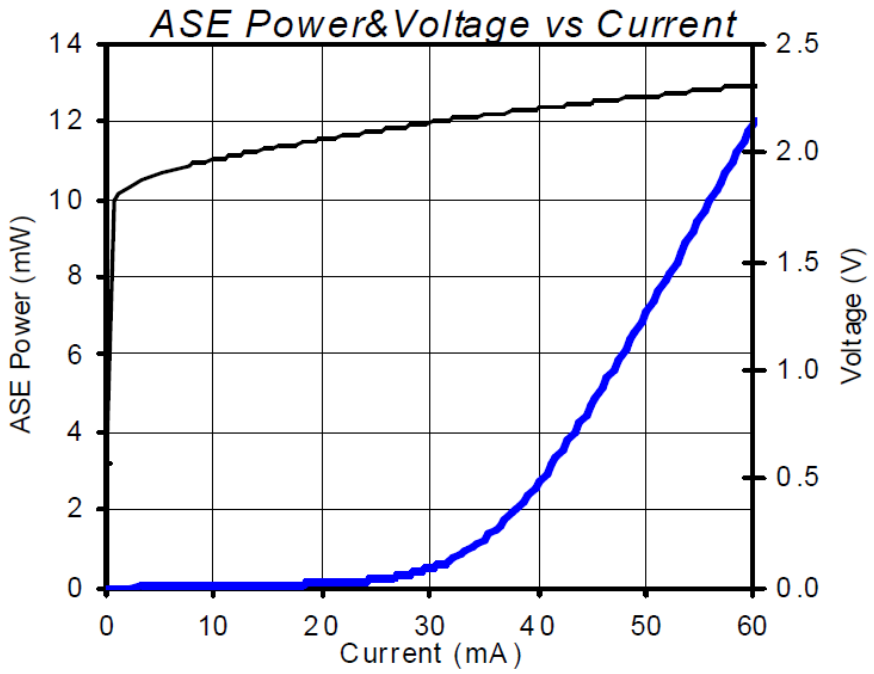
650nm SLEDs (TO56)

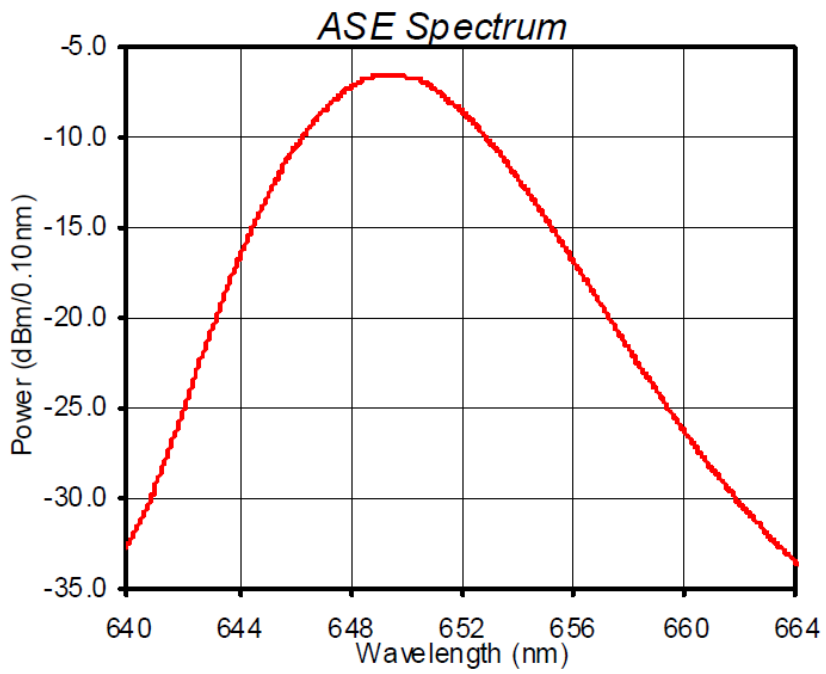
- 12 mW @ 25 °C
- 60 mA @ 2.25 V
- 6 nm bandwidth
- ASE threshold = 35 mA
- Slope effiency = 0.5 W/A
- WPE = 9% (~15% @ 50mW)

Typical Performance

EXS210030-03

(EXS0650-006-10-0B00030)





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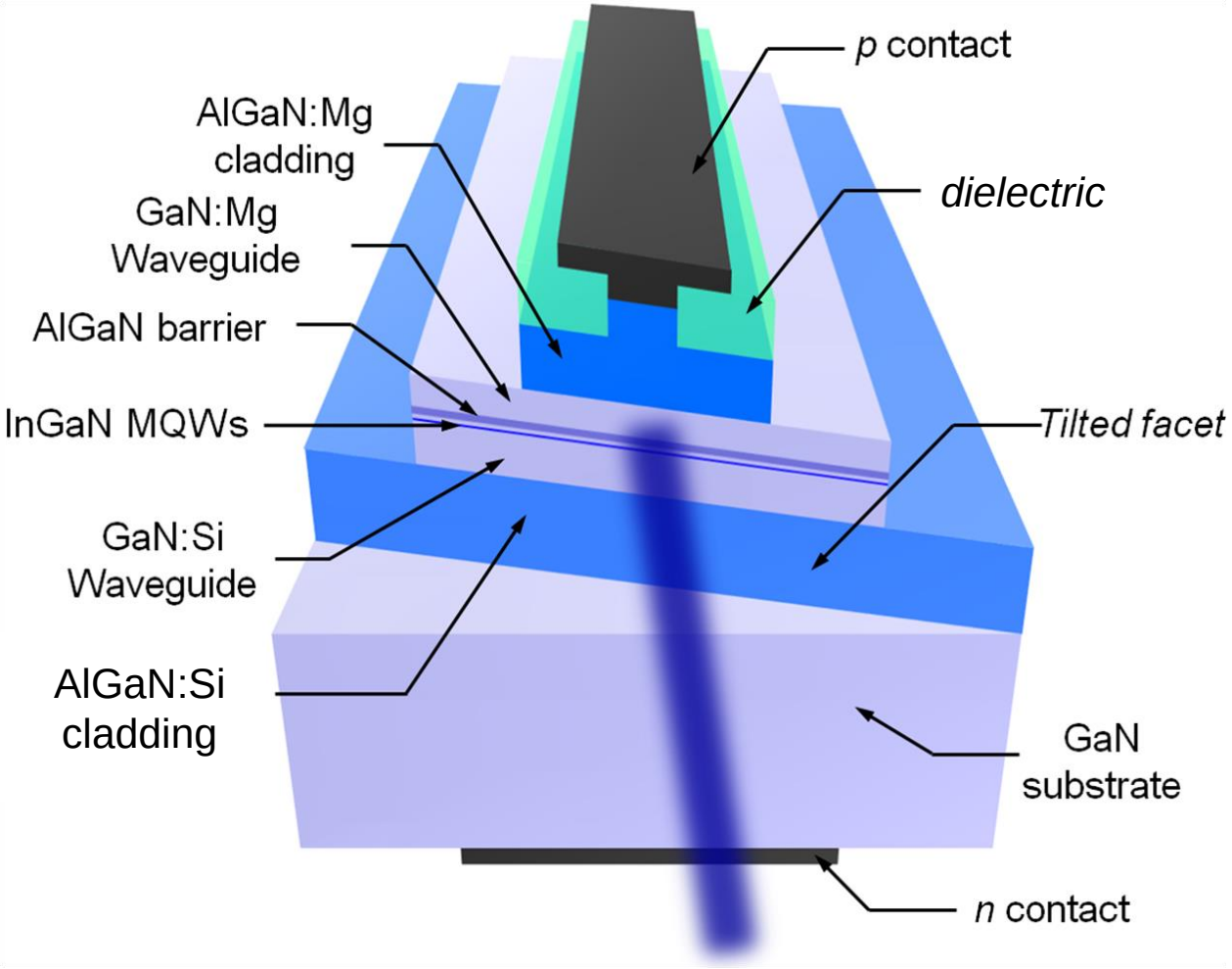
GaN SLED Structure

Blue SLED on c-plane free-standing GaN



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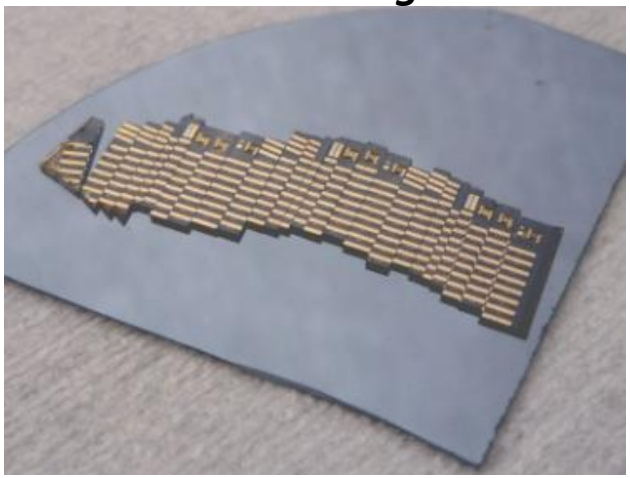
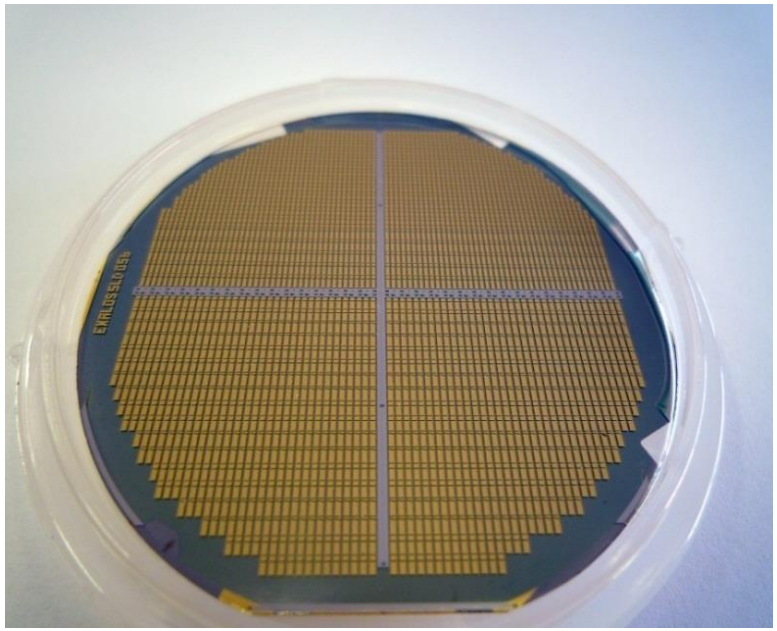
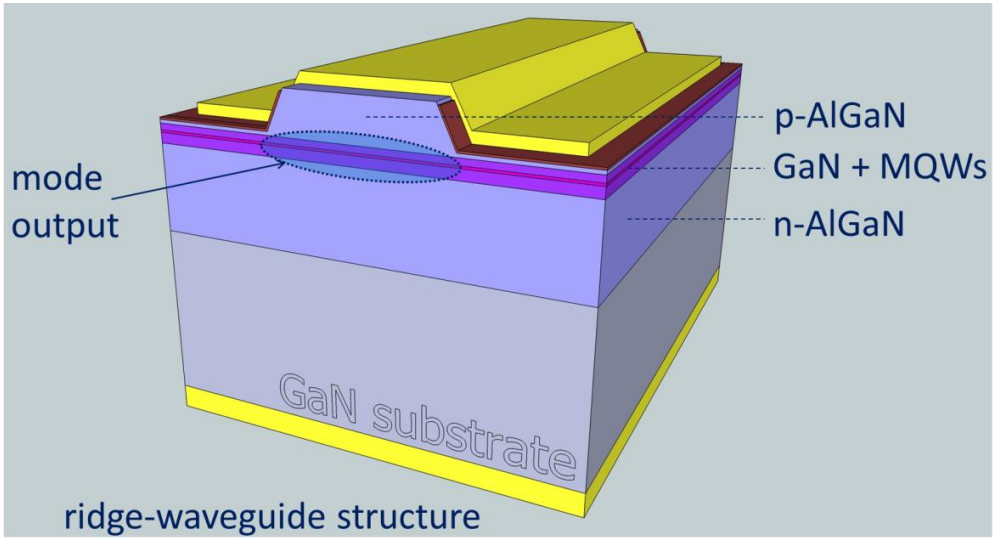
GaN-based SLED Fabrication

- ***Epitaxy on GaN substrate (2'')***
- ***Standard fabrication (like LD)***
  - ***Optical lithography***
  - ***Wet and dry etchings***
  - ***Thin film deposition***

bar cleaving







ridge-waveguide structure

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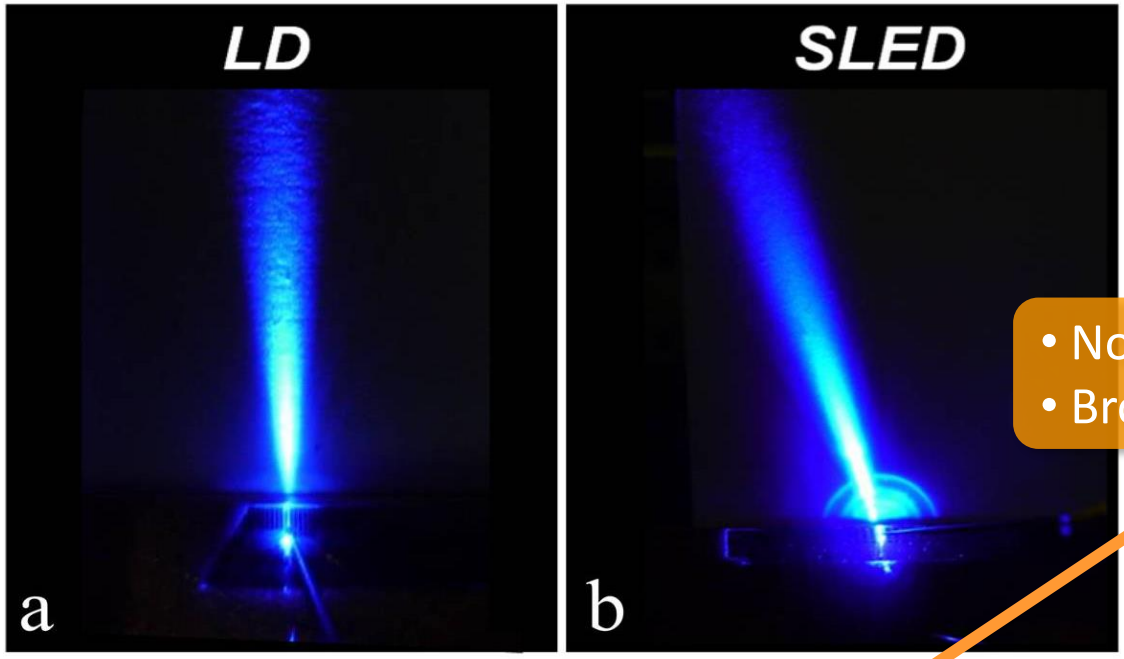
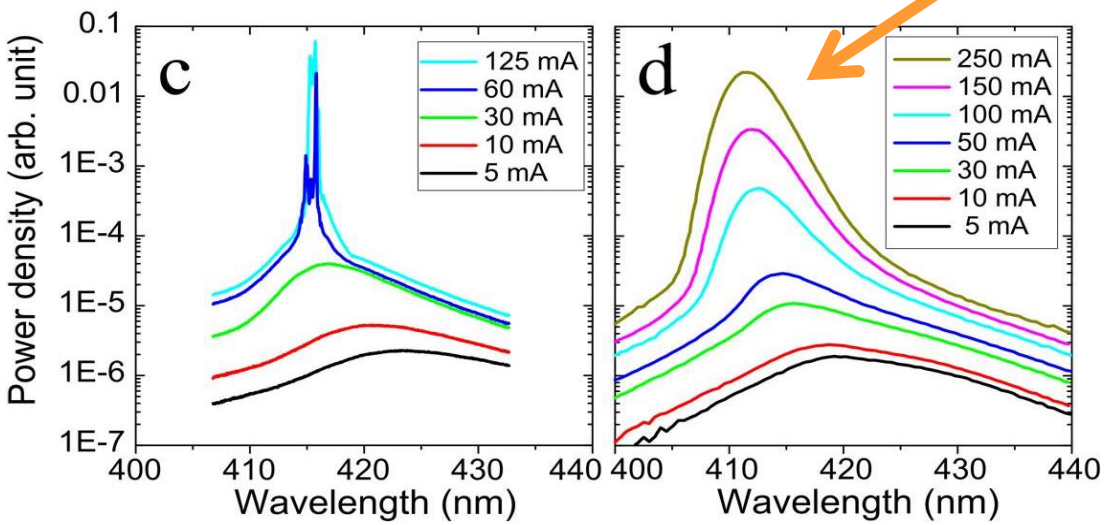
LD/SLED Light Output



- No lasing
- Broad output spectrum



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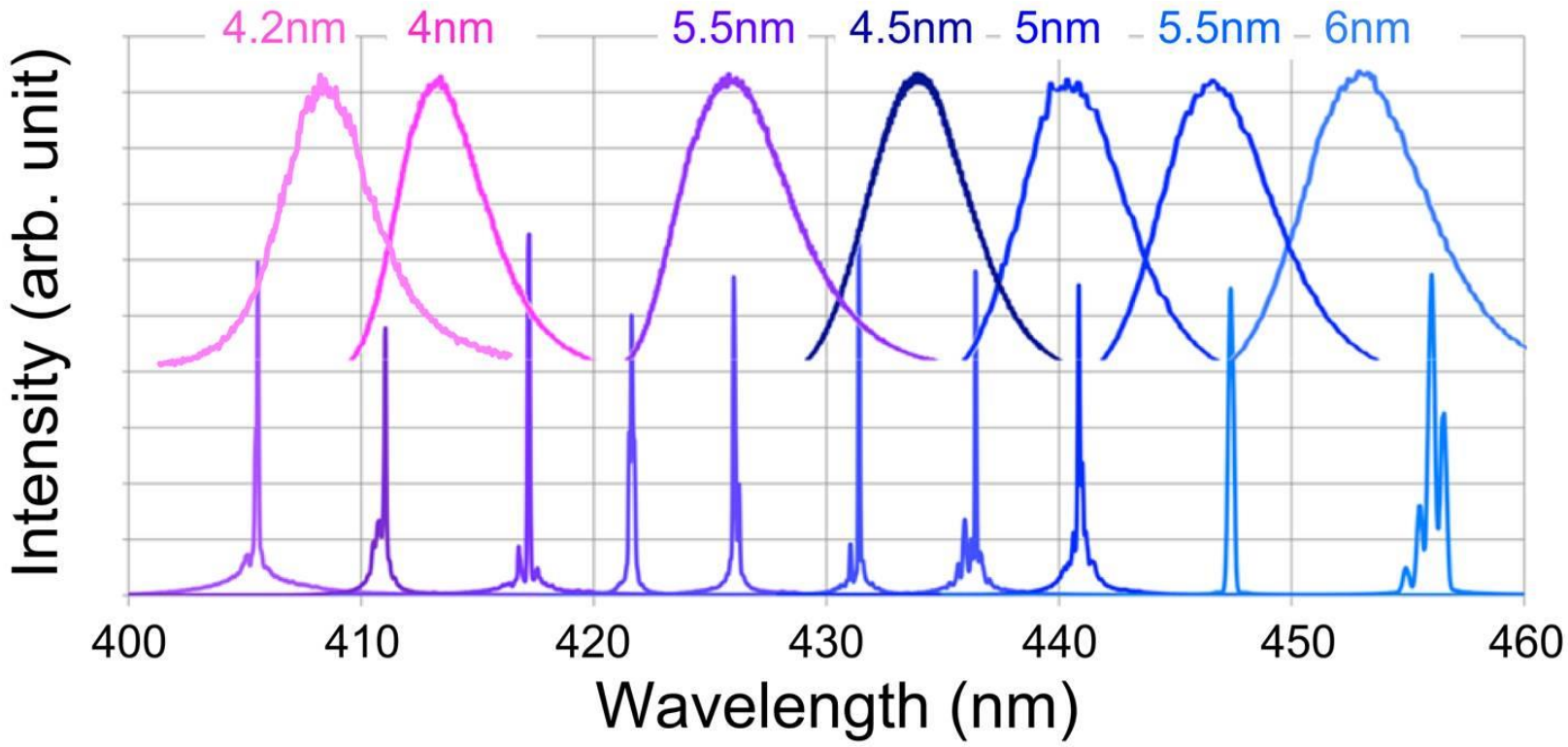
From Violet to Blue SLEDs …

→ shifting wavelength by modifying active QW region (incorporating more Indium)



Typical SLED bandwidth 4-6 nm FWHM
(~16 um coherence length in air)

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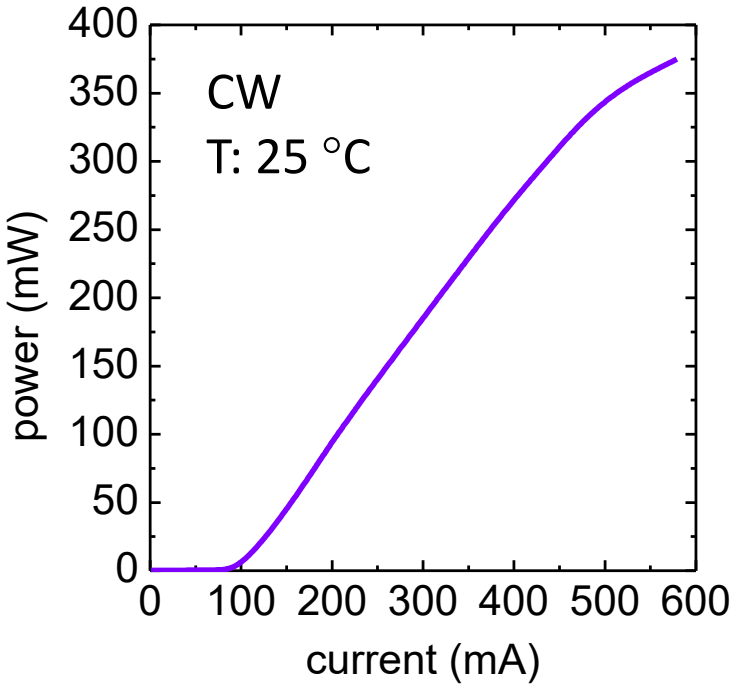
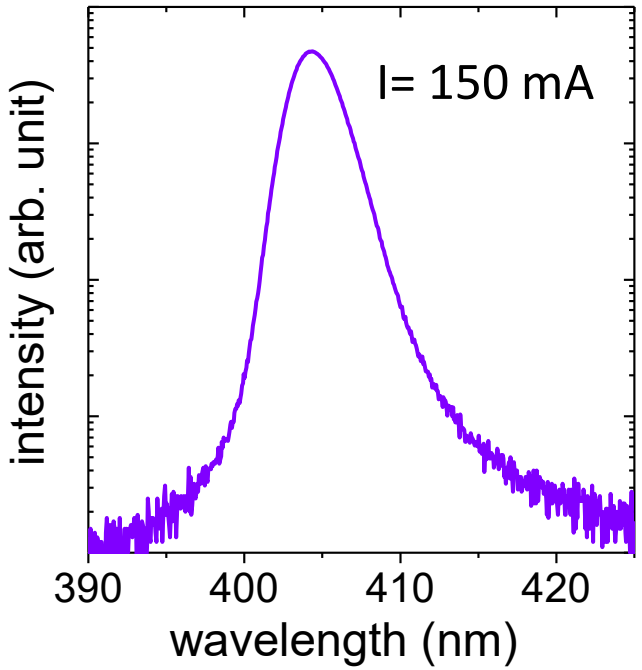
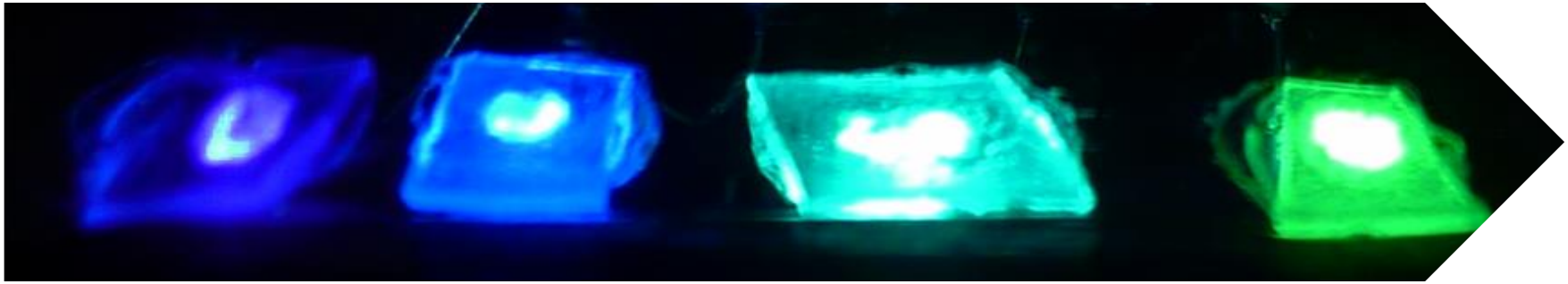
Device Performance: SLEDs

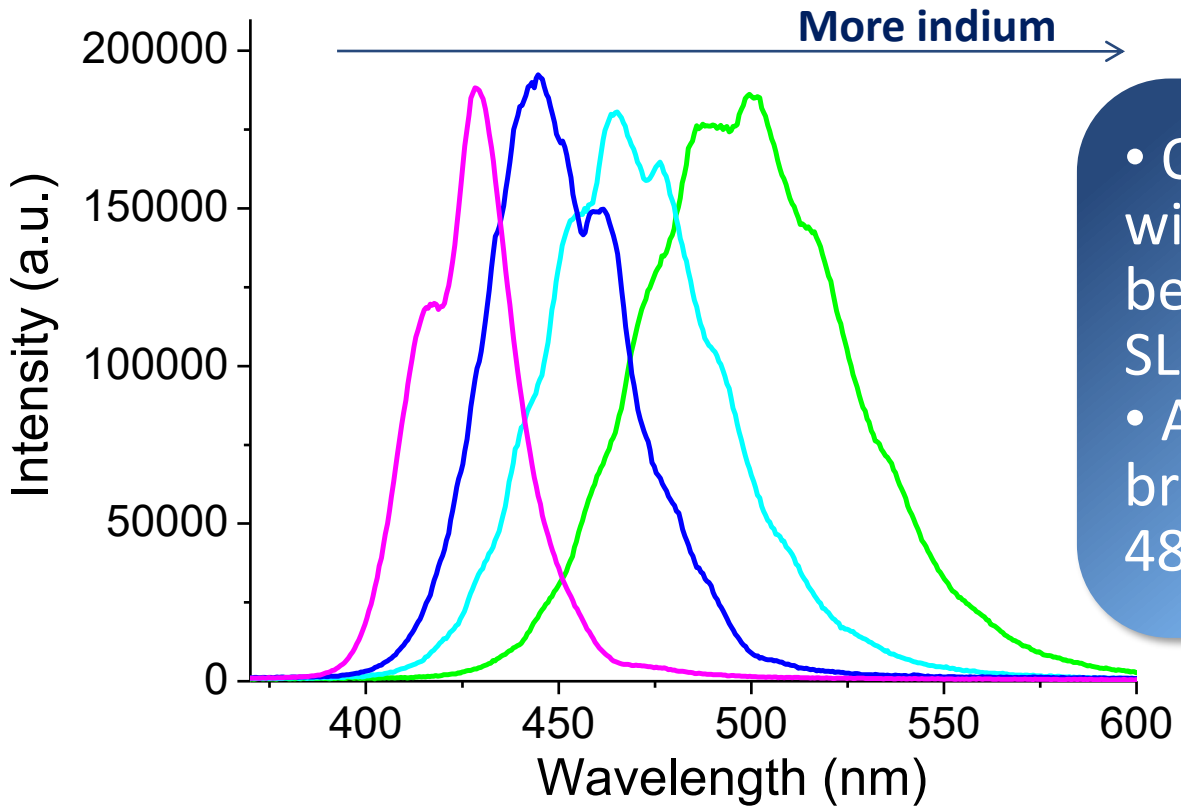




Maximum output powers of 350 mW for an injection current of about 500 mA
Operating voltages below 5 V for a drive current of 100 mA.

… to Cyan and Green SLEDs …





- QW optimization with LED structures before fabricating SLEDs …
- Already realized bright LEDs at 480 nm & 500 nm

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Visible SLEDs Reliability

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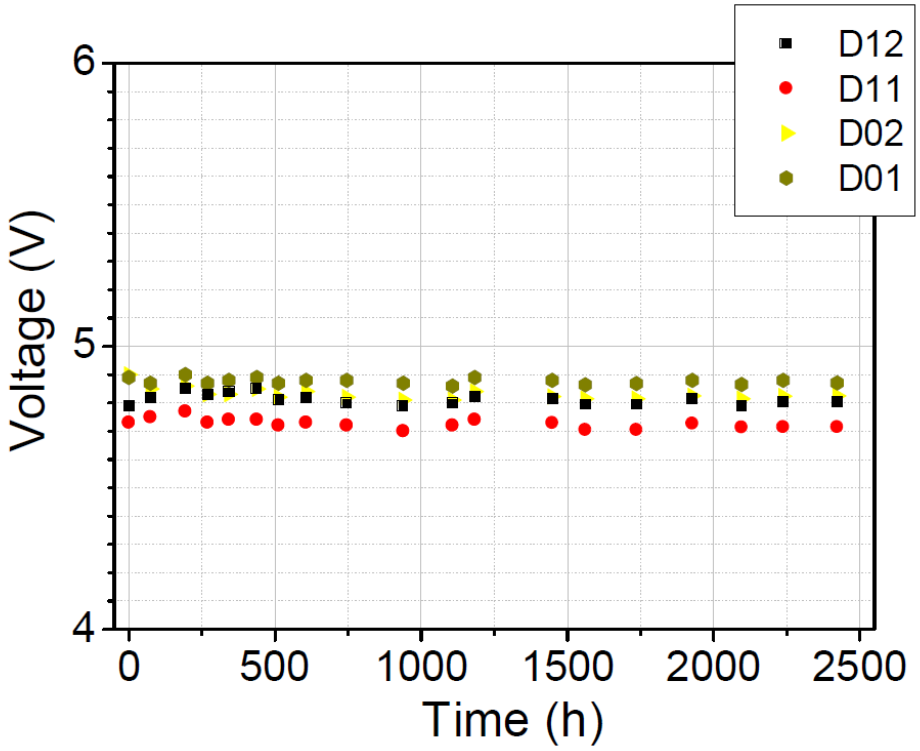
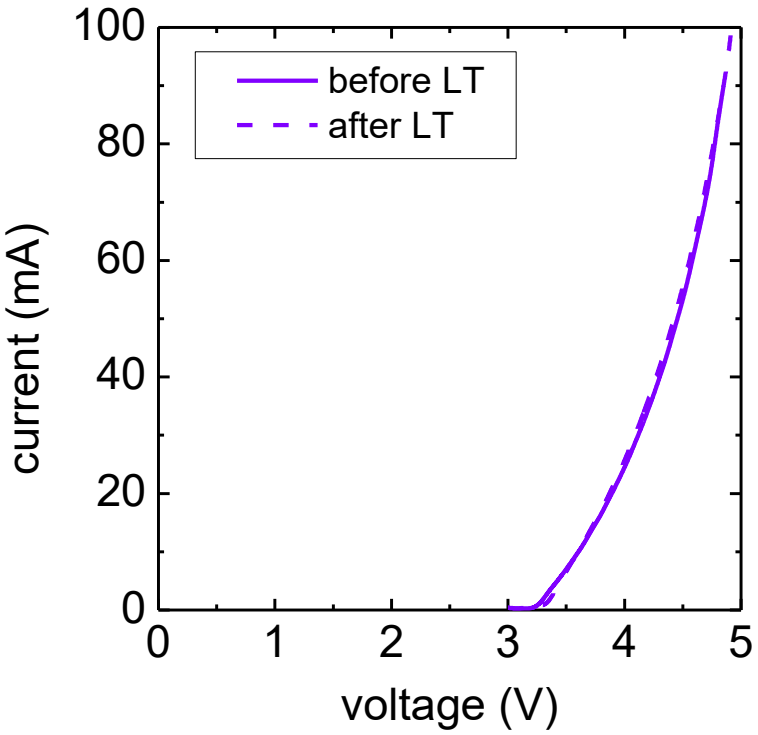
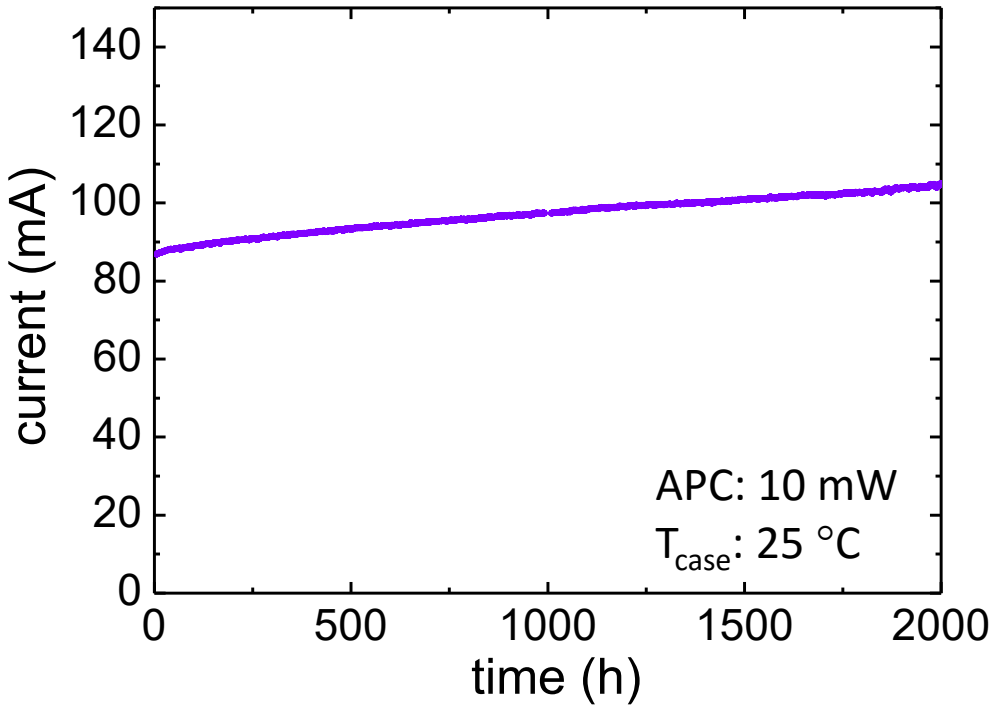
Electrical Long-term Reliability





No electrical degradation observed
during lifetime testing over several thousand hours of operation !

Optical Long-term Reliability (APC)



Modules tested under constant-power mode (Pout = 10 mW ; Tcase = 25 °C)
Degradation rate ~ 0.005 mA/h after 2000h.

Projected lifetime ~ 5000h
(failure criteria defined as a 35% drive current increase)

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Summary

- A SLED is an ideal combination of an LD and an LED,
  → speckle-free laser for illumination & vision systems
- GaAs-based **RED** SLEDs have been fabricated
- GaN-based **VIOLET** and **BLUE** SLEDs have been fabricated
- EXALOS is still working on **GREEN** GaN-based SLEDs
- Key applications for GaN-based SLED are projection systems where good beam quality with speckle-free emission are required
- GaN SLED fullfill similar reliability requirements as LD and can be used in different consumer applications.

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Thank You

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