Development of integrated µLED platforms and their applications in life sciences

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About LEDs

• Solid state lighting

• p-n junction

http://www.upsbatterycenter.com/blog/led/#prettyPhoto
High power LEDs and µLEDs

Until now: large area, high power LED

What about very small LEDs and addressable?

Solid State Lighting

high power LED

- Size: 1 mm
- Osram Opto Semiconductors

1000 mA
100 A/cm²
2.8 – 3.2 V
$P_{\text{out}} > 1 \text{ W}$

Controlling light fields at the micro-/nanoscale

µLED array

- Size: < 100 µm … 1 µm … 100 nm
- TU Braunschweig

1 µA / 1 µm
100 A/cm²
“fully on”
Why are we interested in µLEDs?
Holographic microscopy

A µLED is a good approximation of a point light source

The smaller the light source, the better the resolution capability

\[ U_{z_1}(x_1, y_1) = FT^{-1} \left\{ FT \{ U_0 \{ x_2, y_2 \} \} \exp \left\{ \frac{i2\pi z n}{\lambda} \sqrt{1 - \left( \frac{\lambda f_x}{n} \right)^2 - \left( \frac{\lambda f_y}{n} \right)^2} \right\} \right\} \]
Digital inline holographic microscope

- No lenses
- Miniaturized, compact
- No movable parts
- Real time, continuous monitoring system

- Integration into microfluidic systems
- Robust
- Parallelization
- Low-cost

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Tailored LED: Pinhole LED

A need for small, robust, highly integrated and partially coherent light sources

- Smaller LED $\rightarrow$ better image resolution
- Smaller wavelength $\rightarrow$ better resolution
- Monochromatic light
- InGaN/GaN-based blue emitters ($\lambda = 465$ nm)
- Pinhole LEDs with various sizes from 100 $\mu$m down to 5 $\mu$m

$\mu$LED: GaN semiconductor chip processing
About GaN LED wafer

- p-GaN
- InGaN/GaN MQW
- n-GaN
- Sapphire

\[ \lambda = 465 \text{ nm} \]
GaN LED wafer growth

MOVPE setup at the Institute

Wafers in MOVPE reactor
Pinhole LED characterization

Measured by Benjamin Weigt, Kai Homeyer
Integration of pinhole LED into holographic microscope

- Imaging polystyrene microparticles in comparable size ranges of most cells (5 µm)
- Pinhole LED: enhancing spatial coherency → improving image quality
- Presently, resolution down to 2.6 µm can be achieved

G. Scholz, S. Mariana, A. Waag et al. (2019). MDPI Sensors, 19, 1234
Imaging of biological samples

Clustered pancreatic islets after continuous 48 h monitoring

Neuroblastoma (neuronal cell from cancerous human bone marrow) cell culture measured inside a cell incubator (37 °C, 5% CO₂) for 48 h

G. Scholz, S. Mariana, A. Waag et al. (2019). MDPI Sensors, 19, 1234
Future plan for integrated digital inline holographic microscope

Potential applications:

- continuous monitoring of various other biological samples in an incubator
- automated cell counting
- nanoparticle detection
- 3D tomographic imaging
- pixel super resolution imaging
  …
Next step: further miniaturization

- Using 3D architecture of nanopillars
- Added value: can be embedded onto flexible substrate

Vertical GaN Nanowires and Nanoscale Light-Emitting Diode Arrays
for Lighting and Sensing Applications

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ABSTRACT: For various lighting and sensoric sensor systems, vertically aligned nanowires (1D) gallium nitride (GaN) and indium gallium nitride (InGaN)/GaN-based light emitting arrays with sub-200 nm feature sizes (height of 9 nm) were investigated using scanning electron microscopy (SEM), high-resolution transmission electron microscopy (HRTEM), and time-of-flight secondary ion mass spectrometry (TOF-SIMS). In the nanoscale, GaN nanowire arrays with a height of 9 nm and an aspect ratio of 1:5 were achieved to a specified large area of (3 x 3 mm²). Spectroscopic characterization of the nanowire-based light emitting arrays in room temperature was performed and the results show a clear threshold voltage at a wavelength of 480 nm. Thus, using 1D nanowires transistors outperform 1D GaN-based nanowire transistors in a number of decisive attributes such as higher gains, but considerably lower performance and lower performance density compared to these nanowires. The 2D GaN nanowires arrays have a high light output in the near-infrared range of 9 nm and a high efficiency of 9% for room temperature, which can be realized using advanced techniques of nanofabrication. These nanowire arrays can be used in various applications such as nanoscale light emitting diodes (LEDs) with high efficiency for lighting and sensing applications.

1. INTRODUCTION

In recent years, various semiconductor nanowires have been extensively developed and integrated into different electronic systems. Among them, semiconducting nanowires based on group-III-nitrides, such as InGaN/GaN nanowires, have been extensively investigated for their high efficiency and uses in various light-emitting devices, such as light-emitting diodes (LEDs) and laser diodes (LDs). However, despite the advantages of nanowires, the fabrication of nanowire-based devices is still a challenge. In this work, we report the growth of vertical nanowire arrays using a metal-organic chemical vapor deposition (MOCVD) technique. These nanowire arrays are characterized using advanced nanofabrication techniques and their optical and electrical properties are investigated. The results show that the nanowire arrays have a high efficiency of 9%, which can be realized using advanced techniques of nanofabrication. These nanowire arrays can be used in various applications such as nanoscale light emitting diodes (LEDs) with high efficiency for lighting and sensing applications.
Conclusion

- Micro-/nanoLED array as reliable light sources for life sciences application (i.e., lensless microscope) have been developed
- GaN nanoLEDs using 3D architecture can be as small as 100 nm
- Integration of pinhole LED into lensless microscope enhance the imaging capability

Outlook

- Flexible µLEDs
- Start-up Qubedot GmbH and Cluster of Excellence QuantumFrontiers
List of Publications


List of Publications


Thank you for your attention

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