Sony’s blue and green VCSELs for future applications

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GaN-based VCSELs potential applications

- 369nm: Exciting Yb+
- 405nm: Curing Resin
- 450nm: Exciting Phosphors
- 488nm: Exciting GFP w/o stray
- 525nm: Coupled with POF

- 2D/3D printer
- Chip sized
- 369nm
- Atomic clock
- Precision

- 405nm
- Resolution Speed

- 450nm
- Cost effective
- Narrow divergence

- 488nm
- Better S/N

- 525nm
- POF friendly

- 600nm

GaN ←

GaAs

~600nm

Microsemi.com
3dprintingindustry.com
BMW
AIST.go.jp
TDK.co.jp

Opti. Comm.
Laser Printer
PC mouse...

Sony
Retinal Scanning Displays

QD LASER’s RETISSA display
https://www.qdlaser.com/

SONY’s demo in 2019
https://www.pronews.jp/special/20190822164054.html

How retinal display works
VISIRUM® https://www.qdlaser.com/

Low power VCSELs is in a good match with HMD.
VCSELs; safeness to eyes

EEL (Edge emitting laser)

VCSEL

I-L curves of lasers

Optical output vs. Current

Eye safe limit

1000um

Large overlap

Small overlap
Typical structures for VCSELs

**Typical GaAs-VCSEL**

*From a textbook written by Prof. Iga*

- AlGaAs (Laterally Oxidized)
- AlGaAs Semiconductor DBR
- p-GaAs
- active layer
- n-GaAs
- GaAs substrate

*Metal pads abbreviated*

**The 1st CW GaN-VCSEL**

*T.C.Lu@NTCU, et. al., APL, 92, 141102(2008)*

- AIN/GaN Semiconductor DBR
- Oxides Dielectric DBR
- ITO
- SiO2 (anti-guide)
- p-GaN
- active layer
- n-GaN
- GaN substrate

*Metal pads abbreviated*

<table>
<thead>
<tr>
<th>Reflectors</th>
<th>Semiconductors</th>
<th>Hybrid</th>
</tr>
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<tbody>
<tr>
<td>Cavity Length</td>
<td>&lt;a few λ via conductive DBR</td>
<td>5λ via ITO intra-cavity layer</td>
</tr>
<tr>
<td>Contact</td>
<td>Selective Oxidation of AlGaAs</td>
<td>Anti-guiding</td>
</tr>
<tr>
<td>Optical confinement</td>
<td>Selective Oxidation of AlGaAs</td>
<td>Partial insertion of Insulator</td>
</tr>
<tr>
<td>Current confinement</td>
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</tbody>
</table>

*Low hall conductivity in AlN*
Materials used for DBR* mirrors

**Distributed Bragg Reflectors**

**GaAs/AlAs DBR**

- GaAs substrate

**GaN/AlInN DBR**

- Meijo, Staanley
- Thickness change <1%

**Dielectric (SiO2/Ta2O5) DBR**

- Nichia, Xiamen, UCSB

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**Graphs:**

- **GaAs/AlAs DBR**
- **GaN/AlInN DBR**
- **Dielectric (SiO2/Ta2O5) DBR**
Dilemma of cavity length

① Diffraction loss

Diffraction loss per round trip [%]

$ L : $ Cavity length [μm]

Optical confinement

② Mode spacing

Mode spacing [nm]

$ L : $ Cavity length [μm]

Long cavity

Gain spectrum

Longitudinal modes

CMP determines Cavity length
Curved mirror

Merits with curved mirror
- Nullifies diffraction loss → higher Q
- Allows longer cavity with dense longitude modes → higher Q, yield of devices
- Immunizes the tilting of mirror → higher Q, yield of devices

Curved mirror fabrication

Fabrication process of curved mirror

Patterning

Reflowing

Lens relieving

DBR deposition

Resin (Φ ~ 50μm)

GaN substrate

Dimensions and morphologies

Confocal microscope

AFM

TEM

The device structure

- **SiO₂/Ta₂O₅ DBR 11.5 pairs**
- **SiO₂/Ta₂O₅ DBR 14 pairs**
- **ITO**
- **n-electrode**
- **p-electrode**
- **p⁺-GaN**
- **p-GaN**
- **InGaN/GaN 4QWs**
- **n-GaN**

**Light**

**Φ_{ap} : 3~8 μm**

**ROC : 52~82 μm**

**20~30 μm**

T. Hamaguchi, et. al., Scientific Reports, 8, 10350 (2018)
Low threshold blue VCSELs

$R_t = 99.83 \%$ (9.5 pairs)

$\Phi_a = 3 \ \mu m$

$2\omega_0 = 1.8 \ \mu m$

$(R = 30 \ \mu m)$

$I_{th} = 0.25 \ [mA]$

$J_{th} = 3.5 \ [kA/cm^2]$

$P_{max} = 2.7 \ [mW]$

The lowest threshold current for GaN-VCSELs

T. Hamaguchi et al. APEX, to be published
NFP

Picture

Cross sectional plot for NFP

- NFP exhibits the Gaussian-like profile.
- The standard deviation is agreed with the theoretical value.

\[ 2\sigma = \sqrt{\frac{\lambda}{n\pi}} \sqrt{LR - L^2} \]

\[ \sigma : \text{standard deviation} \]

\[ R = 69 \mu m \]
\[ L = 28 \mu m \]
\[ \lambda = 450 \text{ nm} \]
\[ n = 2.5 \]
Emission divergence

- FFP FWHM is inversely proportional to NFP σ, verifying lateral optical confinement is implemented by the incorporated curved mirror.
High output Blue VCSELs

$R_i = 99.11\%$  
(7.5 pairs)

$\Phi_a = 8\ \mu m$

$2\omega_0 = 2.5\ \mu m$  
($R = 53\ \mu m$)

$P_{max} = 15.4\ [mW]$  
$WPE_{max} = 9.2\ [%]$

$I_{th} = 4.0\ [mA]$  
$J_{th} = 8.0\ [kA/cm^2]$  
$\eta_s = 0.76\ [W/A]$  
$\eta_d = 27\ [%]$

Blue EEL is of WPE greater than 40%.

M. Murayama of Sony, Plenary talk in LDC2019, OPIC2019

Sony Corporation
Transverse mode control with curved mirror structure

Calc.

\[ \frac{\Delta n_{\text{eff}}}{n} = 2.9 \times 10^{-3} \]

I-L

Power [mW]

0 \quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7

Current [mA]

RT-CW

\[ \Phi_a = 4 \, \mu\text{m} \]

\[ 2\omega_0 = 2.5 \, \mu\text{m} \]

\[ (R=53 \, \mu\text{m}) \]

\[ J_{\text{th}} = 9.5 \, \text{kA/cm}^2 \]

Spectrum

Intensity [dB]

Wavelength [nm]

RT-CW

I=6 mA

P_s=3.2 mW

30 dB

FFP

Intensity [a.u.]

Angle [degree]

RT-CW

I=6 mA

I=5 mA

I=4 mA

I=3 mA

I=2 mA

H. Nakajima, et. al., APEX, 12(8), 2019
Arrayed Blue VCSELs

CONTENTS NOT SHOWN
CW operation of Green VCSELs on \{20-21\}-GaN

CONTENTS NOT SHOWN