Vers une source UV à partir de la génération d’harmonique dans des guides GaN.

M. Gromovyi, F. Semond, J. Brault, P. Baldi, J-Y. Duboz, M.P. De Micheli
CNRS-CRHEA et INΦNI, Université Côte d’Azur, Nice, France
Outline

- Motivation
- History
  - Periodically oriented GaN (PO-GaN)
- Recent results
  - Modal phase matching
  - Low loss waveguides
  - SHG results
- Waveguides designed for UV
- Conclusions and perspectives
Combining nonlinear processes with the electrical injection.

**Applications:** electrically pumped nonlinear processes in the Visible and near IR.

Nonlinear interactions in the Visible and the UV range.

**Applications:** frequency doubling 500nm $\rightarrow$ 250nm with AlN, UV light for the medical application and water treatment.
$\chi^{(2)}$ nonlinear guided wave interactions

- low propagation losses
- phase-matching
Periodically Oriented GaN (S. Pezzagna 2005)

Sub-micron patterning for contra-propagative interactions

Technological limitation – macroscopic surface roughness

SHG (Bell Labs)
0.1% conversion
$1.2 \times 10^{-4} \% \text{ W}^{-1} \text{cm}^{-2}$
\( \chi^{(2)} \) nonlinear guided wave interactions

- Low propagation losses
- Phase-matching
Low loss planar waveguides = complex waveguides
Low loss planar waveguides: buffer layer

10 dB/cm @633nm

7dB/cm @633nm
Low loss planar waveguides: MBE vs MOVPE

MBE and MOVPE are two main techniques used for growing crystalline AlGaN

**MOVPE**
- GaN 1.0μm
- AlN 15nm
- Al$_{0.75}$Ga$_{0.25}$N 400nm
- AlN 220nm
- Si(111)

**MBE**
- GaN 1.0μm
- AlN 30nm
- Al$_{0.65}$Ga$_{0.35}$N 400nm
- AlN 220nm
- Si(111)
Low loss planar waveguides: MBE vs MOVPE

MOVPE  2cm  MBE

TE0  

TE1  

TE2  

TE0  

TE1  

TE2  

AlGaN  

GaN  

He-Ne laser  

sCMOS camera
Low loss planar waveguides: MBE vs MOVPE

MOVPE

MBE

TE0

TE0

TE1

TE1

TE2

TE2

AlN

GaN

He-Ne laser

TE3 TE2 TE1 TE0 modes
Low loss planar waveguides: MBE vs MOVPE

MOVPE

MBE
Low loss planar waveguides: surface roughness

7dB/cm @633nm

1 dB/cm @633nm
Low loss planar waveguides: surface roughness

MBE

17 nm
-15 nm

y: 30 μm
x: 30 μm

MBE+MOVPE

5.5 nm
-4.1 nm

y: 30 μm
x: 30 μm

1 cm

Propagation losses @ 633nm

1 cm

TM0 7dB/cm

TM1 12dB/cm

TM2 16dB/cm

TM0 <1dB/cm

TM1 <1dB/cm

TM2 3dB/cm
Low loss planar waveguides: surface roughness

MBE

MOVPE

MBE+MOVPE

Roughness autocorrelation function

\[ \sigma^2 (\text{nm}^2) \]

Distance (\(\mu\text{m}\))

0 2 4 6 8 10 12 14

0 5 10 15 20 25 30 35
Ridge waveguide for higher power density

![Waveguide diagrams](image)

**Si(111)**

- GaN MBE 500nm
- Al$_{0.5}$Ga$_{0.5}$N 500nm
- AlN
- Si(111)

- MOVPE
- GaN MBE 500nm
- Al$_{0.5}$Ga$_{0.5}$N 500nm
- AlN
- Si(111)

**Performance:**
- 8dB/cm
- 4dB/cm

**Parameters:**
- 2.5μm
- 2cm
Ridge waveguide for higher power density

- light is injected in the TM00 mode;
- intensity of the scattered light decreases at a rate $4 \pm 1 \text{ dB/cm}$
$\chi^{(2)}$ nonlinear guided wave interactions

- low propagation losses
- phase-matching
Modal (MPM) and quasi phase-matching (QPM)

$\text{Al}_{0.75}\text{Ga}_{0.25}\text{N}$

1.0 $\mu$m

AlN 125nm

Sapphire

$>30\text{dB/cm} @ 633\text{nm}$
Modal phase matching

- **TM0/TM2** for near-IR to visible conversion
- **TM0/TM1** for mid-IR to near-IR conversion
Modal Phasematching: overlap problem

\[ K = \int_{-\infty}^{+\infty} d_{33}(z) E_P^2(\omega, z) E_{SH}(2\omega, z) \, dz \]

Normalized overlap 3%
Modal Phasematching: overlap problem

\[ K = \int_{-\infty}^{+\infty} d_{33}(z) E_P^2(\omega, z) E_{SH}(2\omega, z) \, dz, \]

SHG efficiency x15
Modal Phasematching: overlap problem

\[ K = \int_{-\infty}^{+\infty} d_{33}(z) \varepsilon_P^2(\omega, z) \varepsilon_{SH}(2\omega, z) \, dz, \]
Modal Phasematching: overlap problem

\[ K = \int_{-\infty}^{+\infty} d_{33}(z) E_p^2(\omega, z) E_{SH}(2\omega, z) \, dz, \]

SHG efficiency x10

Modal Phasematching: overlap problem

\[ K = \int_{-\infty}^{+\infty} d_{33}(z) E_p^2(\omega, z) E_{SH}(2\omega, z) \, dz, \]
Modal and quasi phase-matching

>30dB/cm @633nm

1dB/cm @633nm

20dB/cm @633nm
Second harmonic generation results

2% conversion is reached for 400nJ pump energy
## Second harmonic generation results

<table>
<thead>
<tr>
<th>Harmonic wavelength</th>
<th>Harmonic power</th>
<th>Pump power</th>
<th>Conversion efficiency (%/W)</th>
<th>Type of the structure</th>
<th>Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>750nm</td>
<td>0.7nW</td>
<td>0.8mW</td>
<td>0.24</td>
<td>PhC</td>
<td>EPFL Switzerland</td>
</tr>
<tr>
<td>633nm</td>
<td><strong>2.5W</strong></td>
<td><strong>100W</strong></td>
<td><strong>2.5\times10^{-2}</strong></td>
<td>GaN planar waveguide</td>
<td>CRHEA, LPMC France</td>
</tr>
<tr>
<td>760nm</td>
<td>2.2um</td>
<td>120mW</td>
<td><strong>1.5\times10^{-2}</strong></td>
<td>GaN μ-ring on SiO₂</td>
<td>Yale, MIT USA</td>
</tr>
<tr>
<td>800nm</td>
<td>670mW</td>
<td>670W</td>
<td><strong>1.5\times10^{-4}</strong></td>
<td>PePo-GaN planar</td>
<td>Bell Labs USA</td>
</tr>
</tbody>
</table>
Ridge waveguide for higher power density

- light is injected in the **TM00** mode;
- intensity of the scattered light decreases at a rate of **4±1 dB/cm**
Perspectives: AlN for the VIS to UV conversion
(collaboration with CEA-LETI, Grenoble)

VIS 500nm $\rightarrow$ UV 250nm conversion with $100\% W^{-1} \text{cm}^{-2}$ theoretical efficiency
Conclusions and perspectives

- We have made an important progress in understanding propagation losses in AlGaN waveguides.

- Low propagation losses allowed us to demonstrate AlGaN potential for efficient nonlinear interactions using modal phase matching.

- Further improvements are required to realize the structures with polarity inversion.

- Report is one solution.

- Report allows realizing structures for UV generation.
THANK YOU for your ATTENTION!
Any QUESTIONS?