UV-LED based upon AlGaN

by Marcus Pohl
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- Motivations
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  - assembly
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<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1907</td>
<td>Henry Joseph Round observed light emission from inorganic matter if voltage is applied</td>
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<tr>
<td>1957</td>
<td>- restriction on semiconductor</td>
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<tr>
<td>1961</td>
<td>- Robert Biard and Gary Pittman patented the first infrared LED based on GaAs</td>
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<td>1962</td>
<td>- Nick Holonyak Jr. (General Electrics) invented first practical LED</td>
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<td>1972</td>
<td>- M. George Craford invented yellow LED</td>
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History of the LED

1992: Isamu Akasaki invented first UV-LED

Light output per LED as a function of production year
Motivations

- replacement of low-pressure mercury lamps
- replacement of mercury discharge for the excitation of lamp phosphors
Basics of LED

Functionality:

- p-type
- n-type
- hole
- electron
- light
- conduction band
- Fermi level
- band gap (forbidden band)
- valence band

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Basics of LED

Assembly of a LED:

- Epoxy lens/case
- Wire bond
- Reflective cavity
- Semiconductor die
- Anvil/Post
- Leadframe
- Flat spot

Anode

Cathode
Materials for Ultraviolet-LED’s

- Diamond (235 nm)
- Aluminium gallium nitride (AlGaN) (220 nm)
- Boron nitride (BN) (215 nm)
- Aluminium nitride (AlN) (210 nm)
- Aluminium gallium indium nitride (AlGaInN) (210 nm)
AlGaN

Luminescent properties:

- **Al$_x$Ga$_{1-x}$N epilayer**
  - KSU A-37 ($x=0.3$)
  - FWHM: 39 meV
  - $S=52$
  - $T=10\ \text{K}$

- **KSU A-42** ($x=0.5$)
  - FWHM: 51 meV
  - $S=38$
  - $E=4.616\ \text{eV}$
  - $I_{\text{em}}=4.518\ \text{eV}$

- **KSU A-45** ($x=0.7$)
  - FWHM: 59 meV
  - $S=18$
  - $E=5.048\ \text{eV}$
  - $I_{\text{em}}=4.940\ \text{eV}$

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Influence of the Al-content on the band gap:
AlGaN

Electrical properties:
• increase of resistivity with increasing Al-content
• increase of conductivity possible via doping
  – p-type: Mg
  – n-type: Si

<table>
<thead>
<tr>
<th>Al content, x</th>
<th>Resistivity ρ (Ω cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3</td>
<td>0.18</td>
</tr>
<tr>
<td>0.35</td>
<td>2.1</td>
</tr>
<tr>
<td>0.4</td>
<td>190</td>
</tr>
<tr>
<td>0.45</td>
<td>374</td>
</tr>
<tr>
<td>0.5</td>
<td>&gt; 10^5</td>
</tr>
</tbody>
</table>
AlGaN

Influence of Si-doping:

- critical dopant concentration for Si at $1 \times 10^{18}$ cm$^{-3}$ in case of Al-content above 0.4
- doping with Si causes a shift of the PL to longer $\lambda$ and increase in intensity
AlGaN

Difficulty of p-doping:

- emission wavelength higher as band gap emission due to band-to-impurity transitions for e.g. Mg
- in case of low hole density electron flow into the p-layer increases

-> decrease of light-output
AlGaN UV-LED

Assembly of an AlGaN UV-LED

Ni/Au Electrode

Ni/Au

GaN:Mg
Al_{0.87}Ga_{0.13}N:Mg
Al_{0.98}Ga_{0.02}N:Mg
E-Blocking Layer
Al_{0.79}Ga_{0.21}N
Al_{0.87}Ga_{0.13}N
3-layer MQW
n-Al_{0.87}Ga_{0.13}N:Si

ML-AlN Buffer (NH_{3} Pulse-Flow Method)

Sapphire Sub.
AlGaN UV-LED

Band structure of AlGaN in a MQW-LED:
Applications

- replacement of low-pressure mercury lamps
- replacement of mercury discharge for the excitation of lamp phosphors
- water/air purification
- disinfection of surfaces
- medical treatment (dermatologic, light therapy)
Conclusions

• AlGaN demanding material
  – relatively simple n-type doping (Si)
  – difficult p-type doping
  – advantage: band gap engineering possible

• promising future material if problems can be overcome
References

• http://quantum-algorithms.com/waveeng.html
• http://en.wikipedia.org/wiki/LED
• http://www.ecse.rpi.edu/~schubert/Light-Emitting-Diodes-dot-org/chap04/chap04.htm