The Science behind LEDs

IES San Francisco - Emerging Professionals
Feb 19 2015

Willem Sillevis-Smitt
Contents

- LED history and source for further reading
- Summary of process of making LEDs
- In depth on practicalities
LED history - over 50 years

---|---|---|---|---|---|---|---|---
First LED (red) | GaN on sapphire (polycrystalline) | Watt-class White LEDs | Soraa Founded | Soraa founder awarded Nobel Prize in Physics
N. Holonyak, Jr. | P. Maruska | I. Akasaki | | |
First Blue LEDs / LDs | Bulk-GaN based LEDs / LDs | | | |
S. Nakamura | UCSB | | | |
First GaN-on-GaN™ Lighting Product

**First LED**
N. Holonyak, Jr.

**First Blue LEDs / LDs**
S. Nakamura

**First GaN on sapphire**
( polycrystalline )
P. Maruska

**Watt-class White LEDs**
I. Akasaki
LEDs fundamentally more energy efficient

- Incandescents
  95% heat
- Fluorescents
  Max. efficiency ~ 50%
- LEDs
  “ultimate lamp”*

Good LED reading

http://www.nobelprize.org/nobel_prizes/physics/laureates/2014/
Process of making LEDs

LED substrate
Gasses, Materials

LED Epitaxy
MOCVD

Wafer Fabrication
Metals
Thinning
Etching
Masking
Photo Lithography
Metal Evaporation

Singulation
Cutting
Testing
Sorting

LED Base Phosphors

LED Package Assembly
Die attach
Phosphor dispense
Test
Roller coaster at the heart of the LED

n-side

Active layer

Light

p-side
LED Epitaxy - the heart of the LED

- Equipment: MOCVD
- LED materials
  - Gallium
  - Nitride
    - In, Al
- LED wafer submount material
  - Sapphire
  - Silicon Carbide
  - Silicon
  - GaN

Submount wafer
MOCVD

- Very tight process tolerances!
Gallium Nitride - unique material system

- Transparant
- Thermally conductive
- Electrically conductive
- Robust - strong

- Can produce light
Die examples

GaN on Sapphire

GaN on GaN

Hair
Dislocations

- Occur when substrate material and deposition material are not perfectly matched

GaN Substrate

LED GaN

Sapphire Substrate
No dislocations with GaN substrate

GaN on Sapphire
Hetero-epitaxy

GaN on GaN
Homo-epitaxy

1,000x fewer dislocations
Triangular shape best for light extraction

Light needs sharp angle of incidence to escape die

Rectangular Die

Triangular Die
Droop

- Lower efficiency when driving more current densities
- GaN on GaN highly efficient at higher currents
- Higher light density - good for narrow beams and directional lighting

![Graph showing external quantum efficiency vs. forward current density for GaN on GaN™ and Standard LED](image)
Creating white light

Blue
Green
Red
Spectral Distribution - Full Spectrum Sources vs. Non-Full Spectrum Sources

Daylight - Full Spectrum

Incandescent - Full Spectrum

BP2 LED - Not Full Spectrum - only 70%
- Blue primary

VP3 - Full Spectrum
- Violet primary

No UV
Color Conversion

- Light on its way out
  - Converted to different color when hits a phosphor particle
  - Light can be absorbed by a phosphor particle
  - Can also bounce off a phosphor particle
  - Light is shooting through the phosphor layer in basically all directions
  - We want it to be reflected out - never be absorbed

VP3

BP2
Thank you!