Table of contents

- Overview of electroluminescence

- LED (Light Emitting Diode)
  - History of development
  - Technical details
  - Applications

- OLED (Organic Light Emitting Diode)
  - History of development
  - Technical details
  - Applications

- Electroluminescent strings and foils – Light Emitting Capacitor
  - History of development
  - Technical details
  - Applications
Overview of Electroluminescence

- It depends on luminescence

- It is distinct from fluorescence\(^3\)/phosphorescence, chemoluminescence\(^2\), sonoluminescence\(^5\), bioluminescence\(^1\), superluminescence\(^6\), triboluminescence\(^4\), etc.

- It is an optical/electrical phenomenon

- Material emits light in response to an electric current passed through it, or to a strong electric field

- It is result of radiative recombination of electrons and holes in a material
LED (Light Emitting Diode)

History of development

1907  *Henry Joseph Round* (Marconi Labs) „invents the LED“. He finds out that some inorganic substances glow if a electric voltage is impress on them. He publishted his observation in the journal „Electrical World“

1921  Ignorant of *Round’s* invention, *Oleg Vladimirovich Losev* makes the same observations

1927- Losev investigates this effect

1942 and guesses that it is the inversion of *Einstein’s* photoelectrical effect

---

**A Note on Carborundum.**

To the Editors of Electrical World:

Sirs,—During an investigation of the unsymmetrical passage of current through a contact of carborundum and other substances a curious phenomenon was noted. On applying a potential of 10 volts between two points on a crystal of carborundum, the crystal gave out a yellowish light. Only one or two specimens could be found which gave a bright glow on such a low voltage, but with 100 volts a large number could be found to glow. In some crystals only edges gave the light and others gave instead of a yellow light green, orange or blue. In all cases tested the glow appears to come from the negative pole, a bright blue-green spark appearing at the positive pole. In a single crystal, if contact is made near the center with the negative pole, and the positive pole is put in contact at any other place, only one section of the crystal will glow and that the same section wherever the positive pole is placed.

There seems to be some connection between the above effect and the e.m.f. produced by a junction of carborundum and another conductor when heated by a direct or alternating current; but the connection may be only secondary as an obvious explanation of the e.m.f. effect is the thermoelectric one. The writer would be glad of references to any published account of an investigation of this or any allied phenomena.

1951  Satisfactory explanation of the light emission due to the semiconductor and transistor development

1961  *Bob Biard* and *Gary Pittman* (Texas Instruments) find out that gallium arsenide (GaAs) give off *infrared* radiation when electric current is applied. They receive a patent for this diode

1962  *Nick Holonyak Jr.* (General Electric Company and later University of Illinois at Urbana-Champaign) develops *the first practical visible-spectrum LED* in the *red* (GaAsP) and is seen as the “real father of the LED“
1972  \textit{M. George Craford} (Holonyak's former graduate student) invents the first \textbf{yellow} LED and 10x brighter \textbf{red} and \textbf{red-orange} LEDs

1993  \textit{Shuji Nakamura} (Nichia Corporation) demonstrates the first high-brightness \textbf{blue} LED based on InGaN

1995  First white LED by light conversion is present

1997  The white LED is on the market

1999  Agilent Inc. presents a 102 lm/W red LED (55\% ext. efficiency)

2000  5 Watt LED

2007  White LED with a luminous efficacy of 100 lm/W on the market (Seoul Semiconductor Co., Ltd.)
Technical details
Semiconductors:

- indirect bandgap semiconductor:

<table>
<thead>
<tr>
<th>Mat.</th>
<th>$\Delta W_g$</th>
<th>$\lambda_g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>1.12 eV</td>
<td>1100 nm</td>
</tr>
<tr>
<td>Ge</td>
<td>0.7 eV</td>
<td>1770 nm</td>
</tr>
</tbody>
</table>

$$E_g = \frac{h \cdot c}{\lambda_g} = \frac{1240 \text{ (nm \cdot eV)}}{\lambda_g}$$

- direct bandgap semiconductor

<table>
<thead>
<tr>
<th>material:dopant</th>
<th>color</th>
<th>energy gap $E_g$ [eV]</th>
<th>wavelenght $\lambda_g$ [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GaAs:Si</td>
<td>infrared</td>
<td>1.3 - 1.4</td>
<td>800 - 950</td>
</tr>
<tr>
<td>GaP:Zn,O</td>
<td>red</td>
<td>1.8</td>
<td>700</td>
</tr>
<tr>
<td>GaAs$<em>{0.6}$P$</em>{0.4}$</td>
<td>red</td>
<td>1.9</td>
<td>660</td>
</tr>
<tr>
<td>GaAs$<em>{0.35}$P$</em>{0.65}$:N</td>
<td>orange</td>
<td>2.0</td>
<td>635</td>
</tr>
<tr>
<td>GaAs$<em>{0.15}$P$</em>{0.85}$:N</td>
<td>yellow</td>
<td>2.1</td>
<td>590</td>
</tr>
<tr>
<td>GaP:N</td>
<td>green</td>
<td>2.2</td>
<td>565</td>
</tr>
<tr>
<td>SiC:Al,N</td>
<td>blue</td>
<td>2.6</td>
<td>470</td>
</tr>
<tr>
<td>InGaN</td>
<td>blue</td>
<td>2.7</td>
<td>465</td>
</tr>
<tr>
<td>GaN:Zn</td>
<td>blue</td>
<td>2.8</td>
<td>440</td>
</tr>
</tbody>
</table>
Homo structure (pn-diode)

Double heterostructure (pn-diode)
Fig. 12.16. Typical emission spectrum of GaInN/GaN blue, GaInN/GaN green, and AlGaNp/GaAs red LEDs at room temperature (after Toyoda Gosei Corp., 2000).
Fig. 4.2. Room-temperature current-voltage characteristics of p-n junctions made from different semiconductors.

\[ I_F = \frac{U_B - U_F}{R_V} \]
Fig. 5.5. Light-emitting diodes with (a) planar, (b) hemispherical, and (c) parabolic surfaces. (d) Far-field patterns of the different types of LEDs. At an angle of $\Phi = 60^\circ$, the lambertian emission pattern decreases to 50% of its maximum value occurring at $\Phi = 0^\circ$. The three emission patterns are normalized to unity intensity at $\Phi = 0^\circ$.

[14]
Applications of LEDs

Fig. 9.6. Die-shaped devices: (a) Blue GaInN emitter on SiC substrate with trade name “Aton”. (b) Schematic ray traces illustrating enhanced light extraction. (c) Micrograph of truncated inverted pyramid (TIP) AlGaInP/GaP LED. (d) Schematic diagram illustrating enhanced extraction (after Osram, 2001; Krames et al., 1999).

[14] [17]
The white LED

Fig. 19.1. (a) Schematic of additive color mixing of three primary colors. (b) Additive color mixing using LEDs.

Fig. 20.1. LED-based approaches for white sources including single-chip and multiple-chip, di-chromatic, tri-chromatic, and tetra-chromatic approaches.

Fig. 21.1. White sources using phosphors that are optically excited by UV or blue LEDs.
Advantages of using LEDs

- LEDs produce more Lumen/Watt than incandescent bulbs
  - useful in battery powered or energy-saving devices
- The solid package of the LED can be designed to focus its light
- LEDs are dimmable
  - LEDs do not change their color tint like incandescent bulbs which turn yellow
- LEDs are difficult to damage with external shock
- LEDs ideal for use in applications that are subject to frequent on-off cycling
- LEDs can have a relatively long useful life
  - 35,000 to 50,000 hours of useful life
- LEDs can be very small and are easily populated onto printed circuit boards
- LEDs do not contain mercury
Disadvantages of using LEDs

- LEDs are currently **more expensive** (price per lumen)
- LED performance largely **depends on the ambient temperature**
  > **overheating** of the LED package
- The spectrum of **some white LEDs differs** significantly from a **black body radiator**
OLED (Organic Light Emitting Diode)

History of development

1979  *Chin Tang* (Kodak) finds out that organic material glow

1987  *Tang* and *Van Slyke* introduce the first organic LED consists out of thin organic layers

1990  Electroluminescence at polymers was found

1996  CDT (Cambridge Display Technology) gives world's first public demonstration of Light Emitting Polymer devices

2000  Ritek plans to mass produce OLED, Toshiba Corp. plans to produce (organic EL) panels in 2001
Technical details

materials:

Anthracen

[Al(8-hydroxychinolinat)₃]

Polyphenylvinyliden

Eu-Komplexe

LUMO Energy

2a: electron migration

1a: electron injection

Cathode Fermi level

exciton formation

4: light emission

HOMO energy

1b: hole injection

2b: hole migration

Anode Fermi level
Incoherent Light Sources 2008

Electroluminescence Light Sources – OLED

[10] OLED Structure

- Cathode
- Emissive Layer (Organic Molecules or Polymers)
- Conductive Layer (Organic Molecules or Polymers)
- Anode
- Substrate

[10] OLED Structure

- hole transport layer
- electron transport layer
- light emergence
- glass substrate
- organic phosphor
- transparent anode (ITO)
- metal cathode (e.g., MgAg)
Advantages of using OLEDs

- The plastic, organic layers of an OLED are **thinner, lighter and more flexible** than the crystalline layers in an LED or LCD.
- OLEDs are **brighter** than LEDs because the organic layers of an OLED are much thinner than the corresponding inorganic crystal layers of LEDs.
- OLEDs do **not require backlighting** like LCDs.
- OLEDs are **easier to produce** and can be made to **larger sizes**.
- OLEDs have **large fields of view**, about 170 degrees.

Disadvantages of using OLEDs

- **Lifetime** - While red and green OLED films have longer lifetimes (46,000 to 230,000 hours), blue organics currently have much shorter lifetimes (up to around 14,000 hours).
- **Manufacturing** - processes are expensive right now.
- **Water** - can easily damage OLEDs.
Applications of OLEDs
Electroluminescent Strings and Foils
– Light Emitting Capacitor (LEC)

History of development

1936  *George Destriau* observes that zinc sulfide (ZnS) glows if electric voltage is impress on it. He names this effect after Losev – „Lossew-Light“

1950s  First researches because of the development of transparent conductors (ITO)

1960  Focusing on thin-film LEC

1967  Improvements through the use of double layer insulators

1980s  Application to monochromatic displays

Today  Developing of televisions with LECs
Technical details

\[ C = \frac{\varepsilon_0 \cdot \varepsilon_r \cdot A}{d} \]

Materials:

- Electrode 1
- Dielectric
- Electrode 2

LEC discharges itself

Need inverter (30-160 VAC / 50-5000 Hz)

ZnS emits light if polarisation alternates (sine wave)
Electroluminescence Light Sources – Electroluminescent Strings and Foils – Light emitting capacitor
Applications of LECs

[21]
Electroluminescence Light Sources – Electroluminescent Strings and Foils – Light emitting capacitor

Projectumsetzung: www.hoess-design.de

Incoherent Light Sources 2008

Tim Pohle
Thank you for your attention!
References

4. www.kopfball.de/filme/img/040425_a_01.jpg
11. http://scr3.golem.de/?d=0804/OLED-Tischlampe&a=58863&s=1
14. www.lightemittingdiodes.org
15. Hering, Bressler, Gutekunst „Elektronik für Ingenieure und Naturwissenschaftler“, Springer 5. Auflage 2005
References

16. Presentation Fraunhofer Institut Integrierte Systeme und Bauelementetechnologie
18. C. Ronda „Luminescence – From Theory to Applications“, Wiley-VCH 2008
19. S. Murano “OLEDs für Display- und Beleuchtungsanwendungen - Schlüssel für langlebige effiziente Lichtquellen der Zukunft”, Optik und Photonik März 2003 Nr.1 S.30-31
21. Schreiner Vario Light