# Incoherent Light Sources

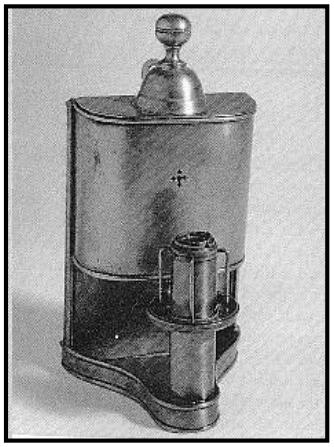
## Contents

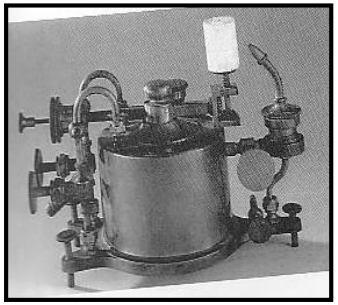


**Lifetime testing at Philips Research Aachen**

# 1. Historical Introduction

## History of Light Generation





| | |
|---|---|
| $1.37 \cdot 10^{10}$ years ago | Big bang |
| $1.3 \cdot 10^{10}$ years ago | First stars and galaxies |
| $1 \cdot 10^{9}$ years ago | Bioluminescence |
| 400000 years ago | Torches |
| 13000 years ago | Primitive stone lamps |
| 5000 B.C. | Fat lamps with wick |
| 1000 B.C. | Candles |
| 600 B.C. | Oil ceramic lamps |
| 280 B.C. | First lighthouse (Alexandria) |
| 1015 | Book of Optics Ibn al-Haytham |
| 1608 | Telescope (refractor) |
| 1668 | Newton telescope (reflector) |
| 1772 | Gas lamps |
| 1783 | Petroleum lamps |
| 1784 | Argand lamp (lamp with a hollow wick) |
| 1826 | Limelight, CaO-Burner “Thermoluminescence” |

# 1. Historical Introduction

## History of Light Generation

**Cologne Newspaper, March, 28th, 1819**

**„Jede Straßenbeleuchtung ist verwerflich“**

**Aus theologischen Gründen**, weil sie als Eingriff in die Ordnung Gottes erscheint. Die Nacht darf nicht in den Tag verkehrt werden.

**Aus juristischen Gründen**, weil die Kosten dieser Beleuchtung durch eine indirekte Steuer aufgebracht werden sollen.

**Aus medizinischen Gründen**, die Gasausdünstung wirkt nachteilig auf die Gesundheit schwachleibiger oder zartherziger Personen.

**Aus philosophisch-moralischen Gründen**, die Sittlichkeit wird durch Gassenbeleuchtung verschlimmert. Die künstliche Helle verscheucht in den Gemüthern das Grauen vor der Finsternis.

**Aus polizeilichen Gründen**, sie macht die Pferde scheu und die Diebe kühn.

# 1. Historical Introduction

## History of Light Generation

| | | |
|---|---|---|
| 1854 | Goebel | Incandescent lamp with bamboo fibres |
| 1858 | Geißler | Hg discharge |
| 1859 | Becquerel | Fluorescent lamp |
| 1878/79 | Swan & Edison | Incandescent lamp with carbon filament (Ediswan) |
| 1900 | Cooper & Hewitt | Patent of mercury vapour lamp |
| 1907 | J.H. Round | Electroluminescence of SiC |
| 1934 | Germer | Low-pressure discharge lamp with luminescent screen |
| 1936 | Destriau | Indirect electroluminescence |
| 1937 | Claude | Ne-discharge lamp with $CaWO_4$ + $Zn_2SiO_4$:Mn |
| 1938 | GE | Fluorescent lamp with $MgWO_4$ + $(Zn,Be)_2SiO_4$:Mn |
| 1948 | | Halophosphate lamp |
| 1959 | GE | Halogen lamp using $I_2$ |
| 1961 | Biard & Pitman | Semi-conductor LED |
| 1971 | Koedam & Opstelten | Tricolour concept |
| 1980 | | Compact fluorescent lamp |

# 1. Historical Introduction

## History of Light Generation


| | | |
|---|---|---|
| 1990 | Friend & Burroughes | First organic LED |
| 1993 | Nakamura | Highly efficient blue (In,Ga)N LED |
| 1995 | Schnick | Nitridic luminescent materials |
| 1996 | Nichia/Osram | White LED comprising (In,Ga)N LED + YAG:Ce |
| 2000 | | White LEDs more efficient than incandescent lamps |
| 2004 | Nichia/Osram/Philips | Warm white LED with (Ca,Sr)S:Eu or $Sr_2Si_5N_8$:Eu |
| 2004 | Mitsubishi | Deep red emitting $CaAlSiN_3$:Eu |
| 2006 | Nichia | Cool white LED with 100 lm/W @ 20 mA |
| 2007 | Nichia | Cool white LED with 160 lm/W @ 20 mA |
| 2010 | CREE | Cool white LED with 208 lm/W @ 20 mA |
| 2011 | Mitsubishi | Yellow emitting nitride phosphor $La_3Si_6N_{11}$:Ce |
| 2012 | Epistar | Warm white LED with 216 lm/W @ 5 mA |
| 2013 | CREE | Cool white LED with 276 lm/W @ 20 mA |
| 2014 | CREE | Cool white LED with 303 lm/W @ 20 mA |
| 2015 | UNESCO | International Year of Light (IYL2015) |
| 2016 | Light&Building FFM | LED dominates lighting market |
| 2019 | UNESCO | International Year of the Periodic Table (IYPT2019) |

# 1. Historical Introduction

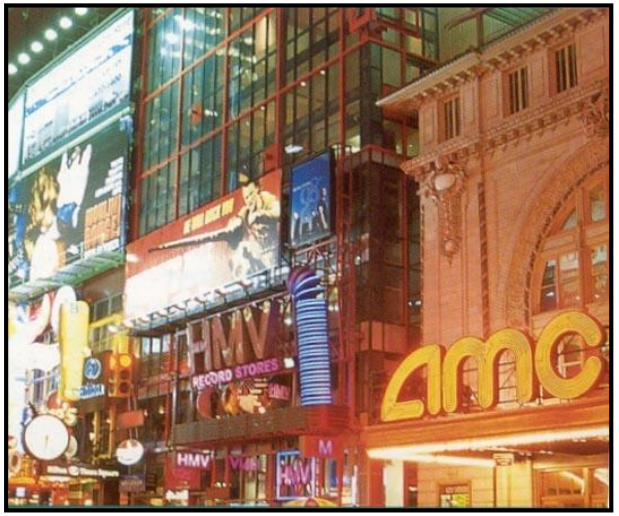
## History of Display Technology

- 1875 George Carey — First TV concept
- 1884 Paul Nipkow — First practical TV
- 1897 Braun — Braun tube
- 1926 Philo Farnsworth — First official TV broadcast
- 1928 A. Hovhannes, J. Blaird — Colour TV
- 1971 James Fergason — LCDs
- 1977 — Gas discharge displays (monochrome orange)
- 1999 Philips — Monochrome PolyLED Display

- 2000 iFire — 17‘‘ ACTFEL Display
- 2004 iFire — 34‘‘ ACTFEL Display
- 2006 — 200 und 300‘‘ Plasma Displays
- 2008 — LED Backlit LCDs
- 2009 Shinoda Plasma — Flexible 125‘‘ Plasma Displays
- 2012 Sony — 4K home projector (3840 x 2160 pixel)
- 2012 NHK/Panasonic — 8K 145‘‘ LCD-Display (7680 x 4320 pixel)
- 2015 — OLEDs Displays
- 2016 Sony — 40‘‘ µ-LED Display (6,220,800 sub-pixel)
- 2019 Samsung — 75‘‘ µ-LED 4K Display
- 2021 Samsung — 88‘‘, 99‘‘, and 111‘‘ µ-LED 4K Display on consumer market

# 1. Historical Introduction

## Light Sources Application Areas Today




- **Interior lighting**
  **→ Halogen lamps → Energy saving lamps → LEDs**

- **Public buildings, Business rooms, Factories**
  **→ Fluorescent tubes → LEDs**

- **Street lighting**
  **→ Sodium lamps → Hg- High Pressure lamps → LEDs**

- **Advertising lighting**
  **→ Fluorescent tubesvLEDs**

- **Signal lighting**
  **→ Incandescent lamp with colour filter → LEDs → laser diodes**

- **Automotive lighting**
  **→ Halogen lamps → Xe/Hg/Zn-Lamps → LEDs → laser diodes (matrix light)**

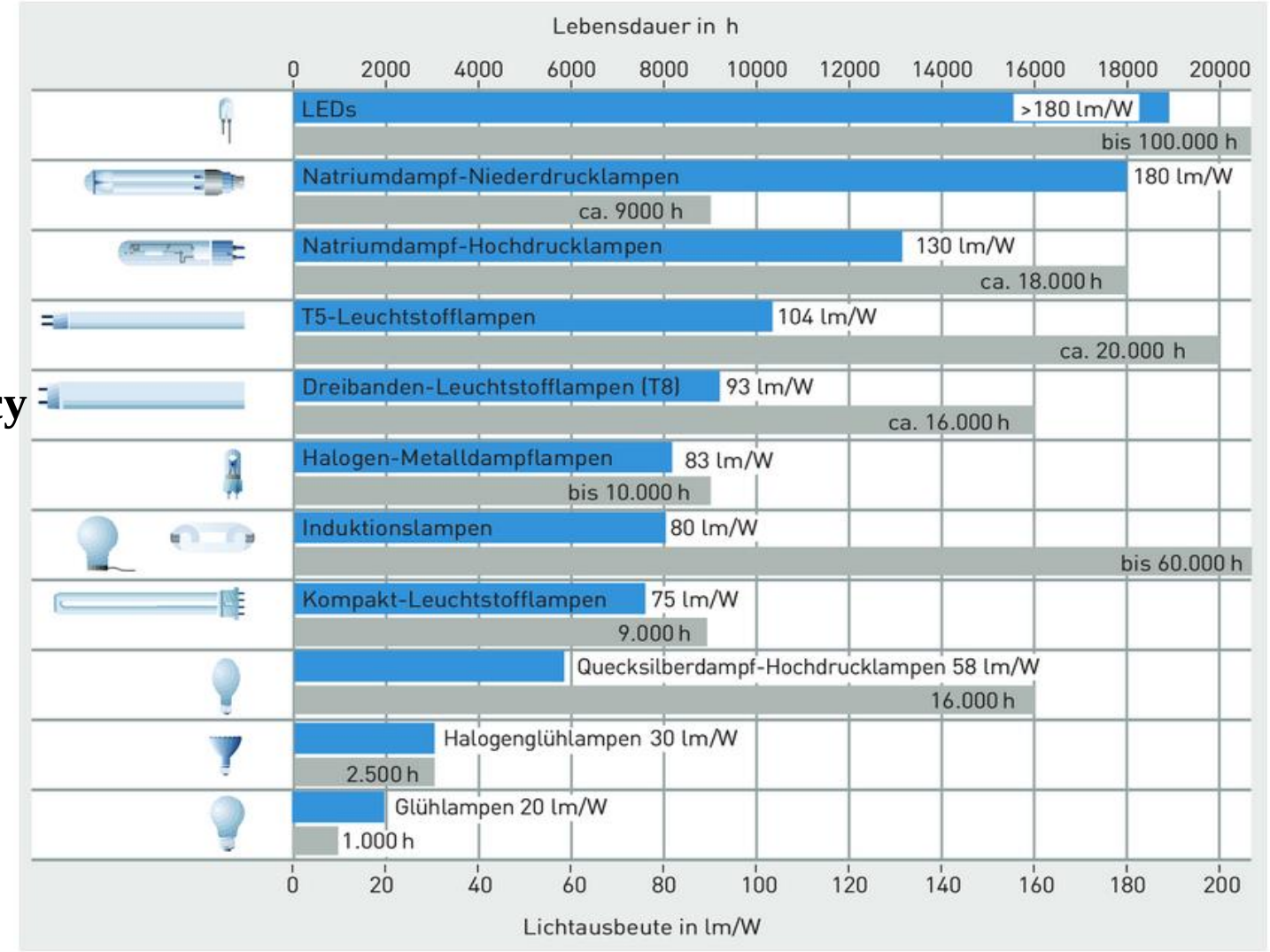
# 1. Historical Introduction: State-of-the-Art

| Light source | Electrical input power [W] | Luminous flux [lm] | Luminous efficacy [lm/W] | Color rendering range |
|---|---|---|---|---|
| Incandescent | 10 – 1000 | 80 – 15000 | 5 – 20 | excellent |
| Halogen | 20 – 2000 | 300 – 60000 | 15 – 30 | excellent |
| Low-pressure Hg discharge | 7 – 150 | 350 – 15000 | 50 – 100 | good |
| High-pressure Hg discharge | 50 – 1000 | 2000 – 60000 | 40 – 60 | good |
| Metal-halide discharge | 20 – 2000 | 1600 – 24000 | 80 – 120 | good to excellent |
| Low-pressure Na discharge | 20 – 200 | 2000 – 40000 | 100 – 200 | poor |
| High-pressure Na discharge | 40 – 1000 | 1600 – 14000 | 40 – 140 | moderate to good |
| Medium-pressure Xe discharge | up to 1000? | up to 40000 | 35 – 45 (lamps)<br>4 – 5 (PDPs) | good |
| White dichromatic Inorganic LED | 1 – 5 | 20 – 500 | 100 – 300 (lab)<br>commercial ~ 180 | good |
| White trichromatic inorganic LED | 1 – 5 | 20 – 100 | 30 – 160 | excellent |
| Organic LED (at 1000 cd/m$^2$) | 15 mW (per cm$^2$) | 0.25 lm (per cm$^2$) | 20 – 100 | good |

# 1. Historical Introduction: State-of-the-Art

## Quality Issues of Light Sources

- **Lifetime (hours)**
- **Luminous efficacy (lm/W)**
- **Wall plug efficiency (%)**
- **Luminance (lm)**
- **Light quality (CRI)**
- **Color point (x, y)**



# References

## Books / Chapters


- K.H. Butler, Fluorescent Lamp Phosphors, University Park, PA (1980)
- A.H. Kitai, Solid State Luminescence, Chapman & Hall, London (1993)
- G. Blasse, B.C. Grabmeier, Luminescent Materials, Springer Verlag Berlin Heidelberg (1994)
- W. Schmidt, Optische Spektroskopie, VCH (1995)
- J.R. Coaton, A.M. Marsden, Lamps and Lighting, Arnold, London (1997)
- D.R. Vij, Luminescence of Solids, Plenum Press, New York and London (1998)
- S. Shinoya, W.M. Yen, Phosphor Handbook, CRC Press (1999)
- A. Zukauskas, M.S. Shur, R. Caska, Introduction to Solid-State Lighting, John Wiley & Sons, Inc. (2002)
- E.F. Schubert, Light Emitting Diodes, Cambridge Univ. Press (2003)
- C.R. Ronda, Luminescence, Wiley-VCH (2008)
- T. Jüstel, S. Schwung, Leuchtstoffe, Lichtquellen, Laser, Lumin., 2nd Ed., Springer (2019)

# References

## Publications


- M. Bredol, U. Kynast, C.R. Ronda, Designing Luminescent Materials, Adv. Mater. 3 (1991) 361
- M. Bredol, U. Kynast, C.R. Ronda, Leuchtstoffe für Kathodenstrahlröhren, Chemie in unserer Zeit 28 (1994) 36
- T. Jüstel, H. Nikol, C.R. Ronda, New Developments in the Field of Phosphors for Lighting and Display Applications, Angew. Chem. 110 (1998) 3250
- T. Jüstel, C. Feldmann, C.R. Ronda, Leuchtstoffe für emissive Displays, Phys. Bl. 56 (2000) 51
- T. Jüstel, J.-C. Krupa, D.U. Wiechert, VUV Spectroscopy of Luminescent Materials for Plasma Display Panels and Xe Discharge Lamps, J. Luminescence 93 (2001) 179
- M. Born, T. Jüstel, Umweltfreundliche Lichtquellen, Physik Journal 2 (2003) 43
- M. Born, T. Jüstel, Chemie und Lichtquellen, Chemie in unserer Zeit 40 (2006) 294
- T. Jüstel, S. Möller, H. Winkler, Luminescent Materials in Ullmann's Encyclopedia of Technical Chemistry (2012)
- T. Jüstel, Anorganische Leuchtstoffe und LEDs, CHEManager 5 (2017) 9